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NOTE ON THE OPTICAL CONSTANTS OF MANGANESE DISTILLED IN VACUUM

By J. B. Nathanson

[Dept. of Physics, Carnegie Institute of Technology, Pittsburgh, Pa. Received Aug. 6, 1930]

The manganese from which the mirrors were obtained, was prepared by Drs. F. M. Walters and J. B. Friauf[1] of the Bureau of Metallurgical Research, Carnegie Institute of Technology. They were essentially interested in the preparation and study of alloys of known composition of iron, manganese, and carbon. Finding the purity of the commercial manganese unsatisfactory for their purpose, they proceeded to purify the manganese by distillation in a vacuum. Dr. Walters states that the total impurities in the distilled manganese are less than one tenth of one percent. Acting upon the suggestion of Dr. Walters, I have determined the optical constants of this metal.

The optical properties of manganese have been studied by several investigators[2] who employed various modifications of the polorimetric method. The distilled manganese was found to be exceedingly brittle and difficult to polish. The final polish was effected on the polishing wheel, first using aluminum oxide, and ending with magnesium oxide. The mirror was then washed with absolute alcohol, and dried with warm air, after which it was immediately placed in a dessicator. Manganese does not take as good a polish as most metals. The surfaces of the mirror

[1] J. B. Friauf, Trans. Amer. Soc. for Steel Treating, *18*, 213; 1930.

[2] H. v. Wartenburg, Verh. d. Deutsch. Phys. Gesell. *12*, 105; 1910.
V. Freedericksz, Ann. d. Phys. *34*, 780; 1911.
J. T. Littleton, Phys. Rev. *33*, 453; 1911.
G. Pfestorf, Ann. d. Phys. *81*, 926; 1926.

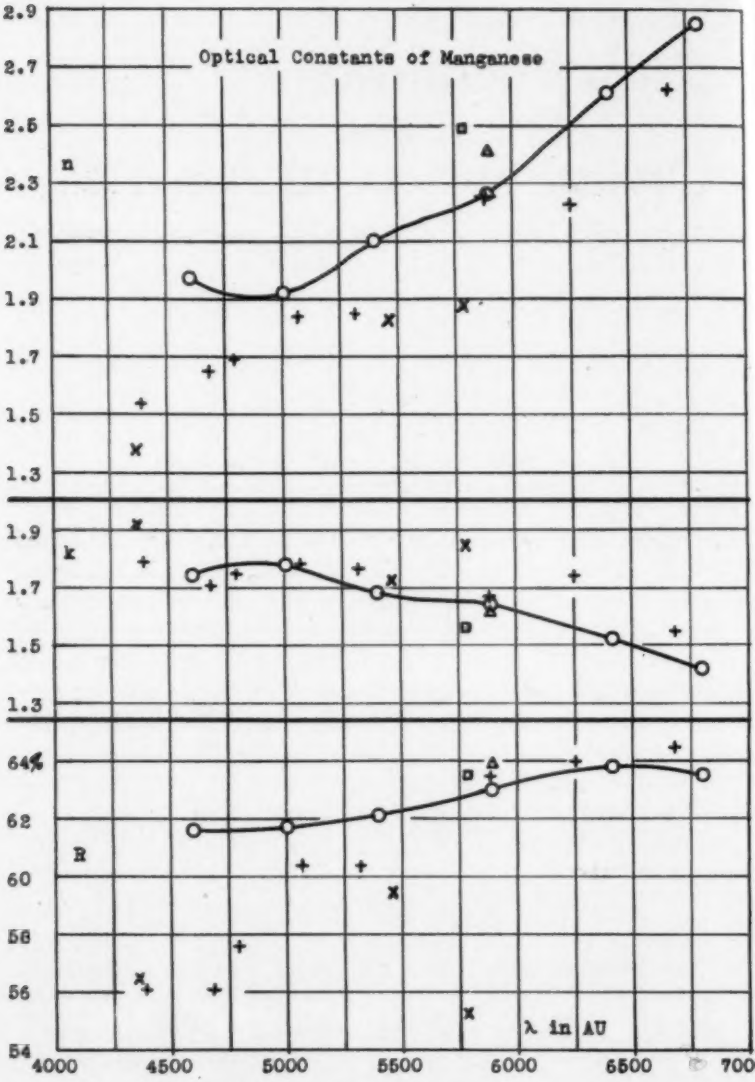

FIG. 1. *Variation with wave length of the optical constants of manganese. Circles represent values for manganese distilled in vacuum. Values obtained by other investigators for manganese not purified by distillation are indicated as follows: crosses, Freedericksz; triangles, Littleton; squares, v. Wartenburg; x's, Pfestorf.*

showed some pits and irregularities. This seems to have been the experience of Freedericksz and Pfestorf.[2]

The experimental method for the measurement of the optical constants was the customary one employing polarized light. When light polarized in a plane making an angle of 45° with the plane of incidence, is incident on a metallic surface, it becomes in general elliptically polarized upon reflection. A measurement of the constants of the ellipse, namely, the phase difference of the two components of the light vector perpendicular and parallel to the plane of incidence, and the ratio of the magnitudes of these components, serve to determine the optical constants. Drude[3] has shown how the refractive index n, and the coefficient of absorption k, might be computed from the observed phase difference and the angle of azimuth of the restored plane polarization. The phase difference was measured by means of a Babinet compensator, while the angle of azimuth was obtained from the setting of the analyzing nicol. Angles of incidence of 45° and 60° were employed, and observations were made for six different wave lengths in the visible spectrum.

The reflecting power R for normal incidence was computed from n and k by means of the relation:

$$R = \frac{n^2(1+k^2)-2n+1}{n^2(1+k^2)+2n+1}. \qquad (1)$$

A summary of the results is given in Table I.

TABLE 1. *Optical constants of manganese.*

λ in AU	n	k	R in %
4600	1.97	1.74	61.6
5000	1.92	1.78	61.7
5400	2.10	1.68	62.1
5890	2.26	1.64	63.0
6410	2.61	1.52	63.8
6800	2.85	1.42	63.5

The results are shown graphically in Fig. 1, the experimental values being indicated by small circles. For comparison purposes the values of the optical constants for the same spectral region, as given by previous investigators,[2] are also indicated.

The values of k for distilled manganese are in fair agreement (as optical constants go) with previous results. The same might be said

[3] P. Drude, Ann. d. Phys. *64*, 159; 1898.

for n and R in the green, yellow and red parts of the spectrum. There is however some divergence in the values of n and R in the blue end. Whether this divergence is to be ascribed to a difference in the purity of the manganese mirrors is difficult to say, since the purity of the manganese used by previous workers has not been stated.

The reflecting power of the distilled manganese is greater in the blue end of the spectrum and slightly less in the red end, than that obtained by previous, investigators. This would seem to indicate that the distilled manganese is "whiter" in color than the specimens used previously. In fact, Freedericksz states[2] that his manganese "mirror was colored light yellow," while v. Wartenburg's mirror had a tendency to assume a brown color upon extended exposure to air. Neither of these characteristics were possessed by the distilled manganese mirrors, the latter always remaining silvery white in appearance.

PARALLAX PANORAMAGRAMS MADE WITH A LARGE DIAMETER CONCAVE MIRROR

By Herbert E. Ives

[463 West St., New York, N. Y. Received July 25, 1930]

In a recent article[1] I have described a method of making parallax panoramagrams by the use of a large diameter lens. The lens used in the experimental test of the method was of 12 inches diameter and 24 inches focal length. It was remarked that while the lens was adequate for verifying the theory used, a lens of considerably larger diameter was really called for in order to produce pictures which would exhibit relief through a satisfactorily large angle of observation.

The practical difficulties in the way of producing a lens of aperture F/1, of 24 inches focal length, which was indicated as desirable for this purpose, are very great, even though, as pointed out, only a narrow diametral strip of the lens is actually needed, and only a few inches length of the lens strip is utilized in forming the elements of any one of the series of stereoscopic views presented by the final picture. Even with these simplifications, it appears, from a study of the design problem, that a suitable lens would demand such a thickness of glass as to make the project of its manufacture compare with the production of a large telescope objective. Some other means of achieving the result, not calling for such a thickness of glass, or such a number of optical surfaces, is desirable if the general method is to be widely used.

In the case of the astronomical telescope the attainment of the largest apertures has been through the use of the reflector in place of the refractor. Similarly, in this problem the desired large diameter and large aperture can be obtained much more practically by *the use of a concave mirror* instead of a lens. The parallax panoramagrams produced by a mirror in combination with a grating slightly separated from the sensitive plate are essentially similar to those produced by a lens, but the variations in arrangement of optical parts and procedure present some features of interest, which will now be discussed.

A characteristic of the mirror is that the incident and reflected light beams traverse the same space, and must be separated. This problem is met in the reflecting telescope by tilting the reflector (Herschel), or by introducing auxiliary reflectors which throw the light to one side (Newton) or through a hole in the concave mirror (Cassegrain, Gre-

[1] J. O. S. A. *20*, 332; 1930.

gory). In the latter designs, the auxiliary reflector is opaque, and completely obstructs a part of the incident light.

None of these means for diverting the reflected light is applicable to the mirror when used for making parallax panoramagrams. The Herschel method is ruled out by the excessive astigmatism exhibited when the mirror is tilted enough to yield an image of any useful size. The other methods are unsuitable for the reason that the auxiliary mirror, while completely out of focus in the telescopic case, will, in the parallax panoramagram, appear suspended at its proper place in space between the observer and the object; it being, of course, the essential

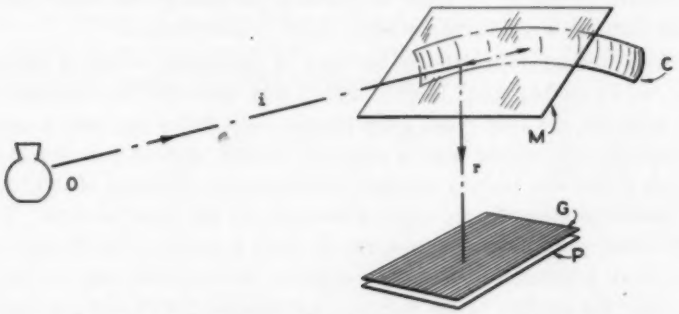

FIG. 1. *Method of using stationary large concave mirror for making parallax panoramagrams.*

characteristic of a perfect panoramagram that objects outside as well as at the focal plane are reproduced.

The remedy is theoretically simple; let the small forty-five degree mirror of the Newtonian telescope be replaced by a semi-transparent reflector extending the whole width of the concave mirror. This arrangement is shown in Fig. 1, where O is the object, C the concave mirror, M the semi-transparent mirror, G the grating, and P the sensitive plate. The path of the light is indicated by the lines i and r. The semi-transparent mirror must, of course, produce no doubling of the image and should therefore have its effective reflecting surface on the side toward the concave mirror and sensitive plate. It may be either a front surface half silvered mirror, or a full silvered surface pierced with many fine holes or slots, of such a size as to be invisible at the distance separating it from the sensitive plate.

The parallax panoramagram negative made by this method is, in its properties and method of utilization, exactly like that made by the

use of a large lens. Thus the positive print made from it must be placed *in front* of the grating for viewing in order to produce stereoscopic instead of pseudoscopic relief. The grating lines must be spaced farther apart in the viewing than in the taking grating, according to the same relationship as that found for pictures made with a large lens. The inversions of the image also work out exactly the same, due to the introduction of an even number of mirror reflections (concave mirror and transparent mirror). Consequently it is necessary, if a picture without inversion is desired, either to introduce another forty-five degree mirror,

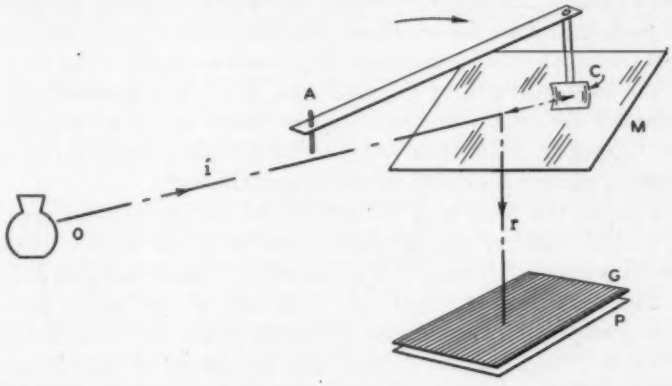

FIG. 2. *Method of using small moving concave mirror for making parallax panoramagrams.*

say in the light path at *r*, or to insert the negative or positive sensitive plate with its glass surface toward the grating. The procedure of copying a pseudoscopic negative by projection back through a similar large aperture system to make a stereoscopic print, described in an earlier article,[2] is of course equally feasible with the mirror as with the lens.

The outstanding advantage of the concave mirror, as contrasted with the lens, is its greater practicability of construction, and relative cheapness. Mirrors of the size and focal length suitable for relief picture making are in fact, commercially made for searchlight projectors. A defect of the concave mirror is the astigmatic aberration of the image at any considerable distance from the axis. This defect will be minimized by the small effective aperture of mirror utilized by the two eyes in any one viewing position. Furthermore, auxiliary lens systems for use between the mirror and the plate, for the purpose of enlarging the

[2] J. O. S. A. *20*, 590; 1930.

area of good definition, have been worked out for astronomical reflectors; possibly similar systems are feasible here.

It is of interest to note that just as either a moving lens or a large lens can be used to make parallax panoramagrams, so a moving mirror apparatus can be constructed by a slight modification of the large mirror scheme. This modification is illustrated in Fig. 2. It differs from the apparatus of Fig. 1 in that in place of a large stationary concave mirror, it uses a small concave mirror, of the same focal length as the large mirror, arranged however to be swung, during the exposure, about an axis, A, through its center of curvature. Upon the completion of its path, the mirror has of course given the sensitive plate the equivalent of the exposure from the single large concave mirror. (This assumes that the large mirror is of spherical curvature. If a parabolic mirror is assumed, the path of the small mirror would not be accurately circular. Actually, since most objects photographed would be nearby, a spherical surface is as near correct as a paraboloid.)

Comparing this moving mirror device with the moving lens devices,[3] it is evident that the characteristic property of the mirror,—that it forms its image on the same side as the object—makes for a more compact and self-contained apparatus. The cost of the optical parts of a camera employing a small moving mirror would be much less than the cost of a large concave mirror. The advantage of short exposure time would however be sacrificed.

[3] J. O. S. A. *17*, 435; 1928.

CRITICAL FREQUENCY MEASUREMENTS IN ANOMALOUS TRICHROMATIC VISION

By H. A. Blair

[Palmer Physical Laboratory, Princeton, N. J. Received Aug. 11, 1930]

ABSTRACT

Critical frequency measurements for the light adapted anomalous trichromatic eye were made on spectra of fourteen intensities. No Purkinje effect was observed. The Ferry-Porter law is apparently obeyed but the branches of the Porter graphs are more numerous than for normal vision. The results are interpreted by Allen's visual reflex theory.

Critical frequency measurements at points from the fovea toward the temporal periphery for three wave lengths in the yellow fall on three distinct curves. The ends of the first two probably mark the boundary of the fovea and the macula lutea respectively. One peripheral normal curve is given.

The writer while a student of Professor Frank Allen set out at his suggestion to obtain information on the Purkinje phenomenon by means of sets of normal curves taken on the foveal and peripheral parts of the eye respectively. On starting to make the measurements he found himself to be an anomalous trichromat and on completing them found no Purkinje effect so the original intention had to be abandoned. The results obtained may, however, be of interest as a study of anomalous trichromatism since no normal curves for this type on spectra of different intensities have been published before as far as the writer is aware.

The measurements were made on spectra obtained from a constant pressure acetylene gas flame by means of a Hilger constant deviation wave length spectrometer. Between the source of light and the collimator was a pair of Nicol prisms by means of which the intensity of the light was controlled. Between the slit of the spectrometer and the eye-piece, which was of the open type, a blackened disc of two sectors of 90° each was rotated by means of an electric motor. An electric chronograph registered the movement of the disc along with the time. Surrounding the eye-piece was a cardboard back-ground of neutral cream color resembling that of the walls of the room. Thus while the readings were taken with the right eye, the left eye was under the same influence of illumination as were both eyes between the readings, that is in ordinary interior daylight.

It was assumed that a measure of the sensation was given by the critical frequency of flicker, and the duration of the stimulus was accordingly measured when the frequency of the stimuli was so great, and just so great, that the stimuli gave a continuous sensation. This duration may be called the critical duration D. $1/D$ gives the number of these stimuli required per second, ie., $1/D$ is the critical frequency of flicker.

To maintain daylight adaptation the readings which occupied about one-half minute each were taken every four minutes so that for over three minutes between readings the eye was exposed to the light of the room. It was found that a second reading on the same wave length did not differ from a first after this interval so it was assumed that the eye recovered its normal condition during the intervals.

The measurements were made in each case during the latter part of the morning, or in the early afternoon, and only on bright days. It was found that the duration for any particular wave length and intensity was frequently the same from day to day, and seldom varied more than 0.0002 or 0.0003 second. At least two measurements were made on each setting, and the mean result was taken. It was found that in general two consecutive readings would agree to 0.0001 or 0.0002 second and were quite frequently identically the same in the brighter parts of the spectrum.

In Fig. 1 are plotted the values of the critical durations with the wave lengths to which they apply. These are not luminosity curves, which would be obtained by plotting $1/D$ along with the wave length, but are commonly called normal curves, since they may be used as reference curves to indicate the magnitude of depression or enhancement effects.

The lower curve was taken with the Nicols parallel, and the intensity under this condition was called 1. The successive curves from bottom to top were taken with decreasing intensities as indicated in the data, the intensity being taken as proportional to the cosine squared of the angle between the Nicol prisms. It should be noted that this relation between the intensities is applicable only to one particular or rather each particular wave length, as an intensity 1 for any one wave length is not necessarily the same intensity as intensity 1 for any other wave length.

It will be readily observed that at no intensity was there a minimum duration obtained except with wave length .580μ. Thus it must be concluded that for the author's eye, when the measurements are made by this method and with daylight adaptation, the maximum brightness of the spectrum lies always between .570μ and .590μ regardless of the intensity of the spectrum. This is in agreement with the results obtained by various observers[1] using different methods.

Allen[2] by the same method, but with a different instrument found a slight shift of the maximum toward the blue as the intensity of the spectrum was decreased. This may be due to a property of the normal eye, or it may be due to a difference in size in the apertures of the spec-

trometers used. The area of the retina stimulated would be determined by this last factor, and since some observers[1] have concluded that the Purkinje phenomenon is absent only within an area subtending one and one-half degrees it may be experienced when a greater area is affected.

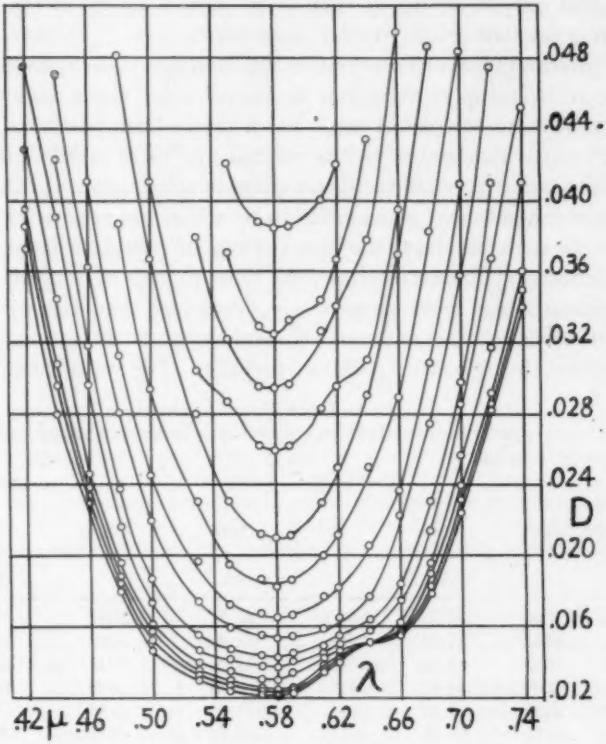

FIG. 1. *Normal foveal curves.*

The curves in Fig. 1 data of Table 1, show clearly that the writer has not the normal type of vision which when graphically represented is characterized by smooth parabola shaped curves.[2] The writer's normal for the highest intensity resembles that of W. A. Anderson[3] and of some others which have been discussed in a recent paper.[4] In this paper were given data on the normal curves of three persons, one color blind, one with anomalous, and the other with normal vision, the measurements having been taken on the same apparatus with the same light source.

It was shown that the normal curve of anomalous vision coincided with that of normal vision in the region of the characteristic elevation (.64μ lower curves, Fig. 1) as well as in the blue and violet. It lay below in the outer red and in the green, indicating greater sensitivity to these colours in anomalous trichromatic than in normal vision. The curve of the color blind subject lay above that of the normal except in the orange, indicating lowered sensitivity for most colors.

The interpretation of these results was summed up as follows:

"The relationship of abnormal to normal color vision may now be formulated more completely than has hitherto been possible. In the nervous visual mechanism of the normal eye there is maintained an exquisite balance between the direct effect of stimulation and the reflex actions of enhancement and inhibition by which the sensitivity is controlled. In color blindness the direct effects of stimulation are considerably reduced in intensity because the reflex process of inhibition is for some reason much more prominently developed than the enhancing action or else the latter is greatly underdeveloped. In anomalous trichromatism the opposite condition prevails. The enhancing actions

TABLE 1.

	$\alpha=00°$		$\alpha=15°$		$\alpha=20°$	
Wave length	D	$1/D$	D	$1/D$	D	$1/D$
		sec.		sec.		sec.
.74μ	0.0341	29.32	0.0350	28.57	0.0361	27.70
.72	.0283	35.33	.0286	34.96	.0292	34.24
.70	.0225	44.44	.0232	43.10	.0240	41.66
.68	.0179	58.65	.0183	54.64	.0190	52.63
.66	.0156	64.10	.0157	63.49	.0158	63.29
.64	.0152	65.78	.0152	65.78	.0152	65.78
.62	.0141	70.92	.0142	70.42	.0143	69.93
.61	.0135	74.07	.0136	73.52	.0138	72.46
.59	.0123	81.30	.0124	80.64	.0125	80.00
.58	.0122	81.96	.0123	81.30	.0124	80.64
.57	.0123	81.30	.0124	80.64	.0125	80.00
.55	.0124	80.64	.0127	78.74	.0130	76.92
.53	.0130	76.92	.0133	75.18	.0136	73.52
.50	.0147	68.02	.0153	65.35	.0158	63.29
.48	.0180	55.55	.0185	54.05	.0188	53.19
.46	.0229	43.66	.0234	42.73	.0238	42.01
.44	.0280	35.71	.0296	33.78	.0308	32.46
.42	.0373	26.80	.0385	25.97	.0395	25.31

TABLE 1. (*Cont.*)

	$\alpha=39°$		$\alpha=50°$		$\alpha=60°$	
Wave length	D	$1/D$	D	$1/D$	D	$1/D$
	sec.		sec.		sec.	
.74	0.0411	24.33	0.0453	22.07	0.0522	19.15
.72	.0318	31.44	.0368	27.17	.0410	24.39
.70	.0257	38.91	.0286	34.96	.0298	33.55
.68	.0196	51.02	.0214	46.72	.0231	43.29
.66	.0163	61.34	.0175	57.14	.0184	54.34
.64	.0152	65.78	.0158	63.29	.0164	60.97
.62	.0147	68.02	.0151	66.22	.0156	64.10
.61	.0143	69.93	.0146	68.49	.0149	67.11
.59	.0134	74.62	.0141	70.92	.0146	66.49
.58	.0130	76.92	.0137	72.99	.0143	69.93
.57	.0131	76.33	.0138	72.46	.0144	69.44
.55	.0135	74.07	.0142	70.42	.0148	67.56
.53	.0140	71.42	.0147	68.02	.0156	64.10
.50	.0162	61.72	.0174	57.47	.0187	53.47
.48	.0196	51.02	.0216	46.29	.0238	42.01
.46	.0245	40.81	.0296	33.78	.0318	31.44
.44	.0344	29.06	.0390	25.64	.0423	23.64
.42	.0428	23.36	.0476	21.00	.0507	19.72

TABLE 1. (*Cont.*)

	$\alpha=70°$		$\alpha=76°$		$\alpha=80°05'$	
Wave length	D	$1/D$	D	$1/D$	D	$1/D$
	sec.		sec.		sec.	
.72	0.0476	21.00	0.0531	18.83		
.70	.0358	27.93	.0409	24.44	0.0484	20.66
.68	.0275	36.36	.0309	32.36	.0383	26.10
.66	.0223	44.84	.0237	42.19	.0289	34.60
.64	.0178	56.17	.0206	48.43	.0250	40.00
.62	.0166	60.24	.0182	54.94	.0212	27.16
.61	.0159	62.89	.0177	56.49	.0200	50.00
.59	.0155	64.51	.0167	59.88	.0187	53.47
.58	.0154	64.93	.0166	60.24	.0183	54.64
.57	.0156	64.10	.0168	59.52	.0187	53.47
.55	.0160	62.50	.0173	57.80	.0195	51.28
.53	.0174	57.47	.0197	50.76	.0231	43.29
.50	.0220	45.45	.0246	40.65	.0294	34.01
.48	.0280	35.71	.0312	32.05	.0387	25.83
.46	.0362	27.62	.0410	24.39		
.44	.0471	21.23				

TABLE 1. (*Cont.*)

	$\alpha=83°05'$		$\alpha=85°$		$\alpha=86°$	
Wave length	D	$1/D$	D	$1/D$	D	$1/D$
	sec.		sec.		sec.	
.68	0.0487	20.53				
.66	.0370	27.02	0.0395	25.31	0.0495	20.20
.64	.0291	34.36	.0311	32.15	.0378	26.45
.62	.0250	40.00	.0296	33.78	.0341	29.32
.61	.0230	43.47	.0283	35.33	.0327	30.58
.59	.0212	47.16	.0262	38.16	.0297	33.67
.58	.0210	47.61	.0259	38.61	.0294	34.01
.57	.0212	47.16	.0262	38.16	.0296	33.78
.55	.0231	43.29	.0287	34.84	.0322	31.05
.53	.0280	35.71	.0304	32.89	.0379	26.38
.50	.0367	27.24	.0410	24.39		
.48	.0482	20.74				

	$\alpha=86°35'$		$\alpha=87°30'$	
	sec.		sec.	
.64	0.0434	23.41		
.62	.0367	27.24	0.0420	23.80
.61	.0344	29.06	.0400	25.00
.59	.0313	31.94	.0386	25.90
.58	.0325	30.76	.0384	26.04
.57	.0329	30.39	.0388	25.77
.55	.0371	26.95	.0421	23.75

are far more highly developed than the inhibitory. Color blindness, therefore, is due primarily to the predominance of inhibitory and anomalous vision of enhancing processes, which in both types may apply to any one, or two, or all three sensations. It is quite possible, consequently, that as many types of anomalous vision may be discovered as there are forms of color blindness."

While in the present case, lacking comparison curves with a normal subject, it is impossible to make definite statements in regard to enhancement or inhibition at various places, some features may, however, be noted. It is remarkable that the duration at .64μ is the same for four different intensities. As far as the writer is aware this has been previously observed only at low intensities and with dark adaptation.[5] An explanation for this condition was suggested by the writer in a previous

paper.[6] The middle curves of the set are more or less smooth much as are those in normal vision or color blindness. In the fourth curve from top the red and blue ends are perhaps greatly enhanced or it may be that the yellow-green is depressed. Similarly in the third the red alone is probably enhanced while in the second the green may be enhanced. It appears possible to conclude that in anomalous trichromatism the

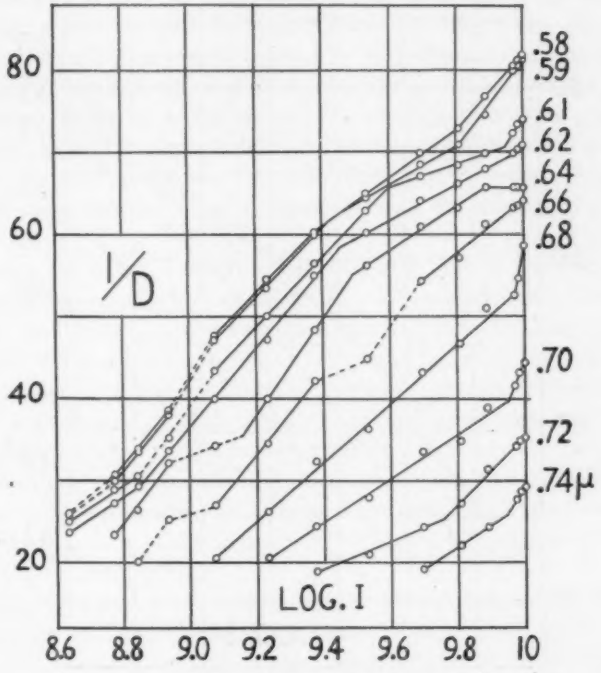

FIG. 2. *Porter graphs.*

anomaly is probably quite different at different intensities, i.e., it does not consist merely in a raised or lowered sensitivity of particular colors throughout the whole range of intensities.

The extent of the anomaly is more easily seen from the curves of Figs. 2 and 3. Here are plotted the values of $1/D$ with the logarithm of the intensity for each wave length. These representations of the Ferry-Porter law are called Porter graphs by Allen. A better method of obtaining these curves would be to measure each wave length through all its intensities successively rather than to measure all wave lengths for

each intensity, at each period of measuring, as was done here. For that reason it is considered more likely that the points which lie off the straight lines of the graphs, as they are drawn, are due to accidental variations of the eyes' condition rather than to a divergence from the Ferry-Porter law, which is:

$$1/D = K \log I + C.$$

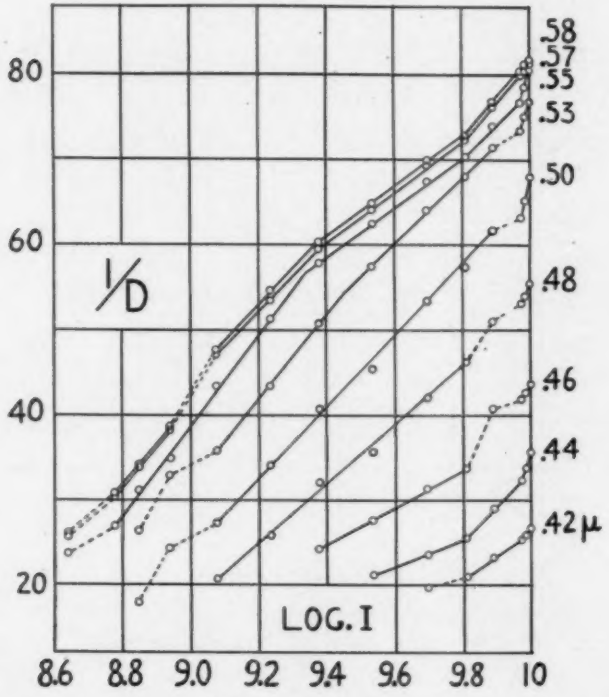

FIG. 3. *Porter graphs.*

It was expected that these curves would in no case have more than three branches since Allen,[7] using a stronger light source, found as many as four for very few colors. It was surprising to find here that four branches occurred quite often, apart from those portions of the graphs which have been joined by broken lines where the points were insufficient in number to define the branches. Whether these portions are short branches or denote a breaking down of the law one cannot say. Allen[7] showed for the normal eye that light intensities belonging to

each branch of these graphs gave different effects of enhancement or inhibition. If the same is true here, which seems probable, the mechanism of enhancement and inhibition in the anomalous eye behaves very differently from that in the normal. The determination of the effects of enhancement and inhibition of the different branches is very necessary for the further description of anomalous trichromatism.

According to Allen's views the sensitivity of the eye in light adaptation is maintained in equilibrium by reflex actions of enhancement and inhibition, these reflexes being evoked by the afferent impulses due to the totality of the light received by the two eyes. These reflexes and the condition of sensitivity of the normal eye resulting from them are such that when this eye is used to obtain a Porter graph the resulting graph conforms to the Ferry-Porter relation. Furthermore, with the normal eye, particular constants in the equations hold for large ranges of intensity.

Adopting the same view here it may be said that in anomalous trichromatism the equilibrium established in light adaptation is also such that the critical frequency measurements conform to the Ferry-Porter law (with the possible exception of the places joined by broken lines, Figs. 2 and 3,) but the constants of the equations are different from those in normal vision and they apply to much smaller regions of intensity. Since the form of the Porter graph is necessarily the indication of the condition of the eye brought about by the mechanism controlling the sensitivity these results are very much in support of Allen's contention that anomalous trichromatism is due to some derangement of this controlling mechanism.

In a previous paper[6] the writer adduced evidence that in normal vision (Allen's eye) the slopes of the different branches of each Porter graph were integrally related. It was supposed there that each branch represented the entrance of a new group of equal elementary effects at a new threshold. These new elements might either be those contributing to the sensation or might be those concerned in the action of Allen's reflex mechanism. The method of obtaining these Porter graphs was not sufficiently accurate for slope measurement but the multiplicity of the branches also denotes, on the above hypothesis, that the reflex mechanism behaves differently from the normal.

The work of W. A. Anderson,[3] an anomalous trichromat, showed that normal color equations were not valid for his eye, He found also that although his eye was depressed or enhanced in sensitivity by stimulating it with different lights, the effects were not of the same magnitude

nor even in the same direction, in all cases, as for the normal eye. He, however, found the equilibrium colors. i.e., those whose action does not change the eye's sensitivity to flicker to be the same as in normal vision. These are further indications that anomalous trichromatism is due to a difference in action of the reflex mechanism.

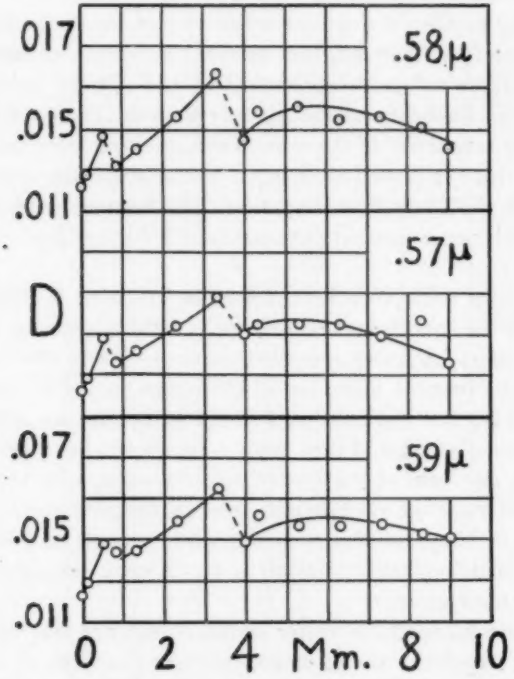

FIG. 4. *Measurements from the fovea outward toward the periphery.*

The recent investigation and proof of the validity of Weber's law by Macdonald and Allen[8] make it seem very much more probable than heretofore that the assumption is true that the critical frequency is a measure of the sensation. One may now more reasonably express the equivalence of the Fechner and the Ferry-Porter laws. Thus in conclusion it may be said that for light of a certain wave length the sensation—intensity relation with light adaptation is quite different for anomalous trichromatism than for normal vision. Fechner's law is obeyed, for the most part at least, but the constants of his equation are valid for shorter ranges of intensity. The multiplicity of branches of the Porter graphs

along with the fact that the normal curves of anomalous vision are similar to the enhanced or depressed normal curves of normal vision leads to classing anomalous trichromatism as due to an abnormality of the visual reflex mechanism.

PERIPHERAL MEASUREMENTS

The measurements plotted in Fig. 4 were made to find the variation of the critical frequency of flicker as a stimulus was directed to points farther and farther from the central part of the retina, the object being to find a suitable part of the periphery on which to make measurements of the luminosity of the spectrum by the critical frequency method.

The same apparatus was used as for the central part of the eye. The light intensity was as for the lowest curve of Fig. 1. To the right of the slit of the instrument was fixed a millimetre scale with a slider. By means of the slider, a bright piece of platinum wire could be moved to any desired position. There was sufficient illumination from the room entering between the eyepiece of the instrument and the slit so that the platinum wire could be distinguished. When the readings were being made the platinum wire was regarded directly with the fovea, so that the light from the spectrometer was falling on the temporal periphery at a position determined by the distance of the platinum wire from the slit.

In Table 2 are given the values of the critical durations for three different wave lengths, and for several positions of the wire. O is the angular distance from the centre of the eye of the portion of the periphery being stimulated. d is the horizontal distance in millimeters of the object fixated from the slit. L is the perpendicular distance from the slit to the lens of the eye; its value in all cases was 61 mm. Thus O is the arc tangent of d/L.

As will be readily seen the plotted values fall on three distinct curves. The curves on the left have a sudden downward fluctuation when θ is a little greater than 30 minutes. This means that the critical duration increases in this particular fashion until a visual angle of about 60 minutes is subtended. The fovea centralis measures from 0.24–0.3 mm, and subtends an angle of from 55–70 minutes.[9] Thus it would appear that this fluctuation occurs at the edge of the fovea centralis, and with the usual assumption that $1/D$ is a measure of the sensation, it may be concluded that the sensation diminishes regularly out to the edge of the fovea centralis, then suddenly increases.

The second set of curves is of the readings taken in the area subtend-

ing from about 94 minutes up to 6 degrees 16 minutes. There seems to be no sudden change at the edge of the rod free area subtending 3 degrees 3 minutes, but it may be that the second fluctuation takes place at the edge of the macula lutea, which subtends 4–12 degrees.[9]

It may be concluded, if these quoted values are valid for the author's eye, that the presence of the rods among the cones does not have any

TABLE 2.

Wave length	d	O	D	d	O	D
	mm		sec.	mm		sec.
.57μ	.0	0°0′	0.0123	0.133	0°7′	0.0129
.58	.0	0°0′	.0122	0.133	0°7′	.0128
.59	.0	0°0′	.0123	0.133	0°7′	.0129
.57	0.533	0°30′	.0148	0.833	0°47′	.0137
.58	0.533	0°30′	.0146	0.833	0°47′	.0132
.59	0.533	0°30′	.0148	0.833	0°47′	.0144
.57	1.33	1°15′	.0142	2.33	2°8′	.0154
.58	1.33	1°15′	.0140	2.33	2°8′	.0156
.59	1.33	1°15′	.0145	2.33	2°8′	.0159
.57	3.33	3°8′	.0168	4.00	3°45′	.0150
.58	3.33	3°8′	.0177	4.00	3°35′	.0144
.59	3.33	3°8′	.0175	4.00	3°45′	.0149
.57	4.33	4°4′	.0155	5.33	5°0′	.0155
.58	4.33	4°4′	.0158	5.33	5°0′	.0161
.59	4.33	4°4′	.0162	5.33	5°0′	.0157
.57	6.33	5°5′	.0155	7.33	6°50′	.0149
.58	6.33	5°5′	.0155	7.33	6°50′	.0156
.59	6.33	5°5′	.0157	7.33	6°50′	.0158
.57	8.33	7°40′	.0157	9.00	8°40′	.0136
.58	8.33	7°40′	.0151	9.00	8°40′	.0140
.59	8.33	7°40′	.0153	9.00	8°40′	.0151

L=61 mm

marked effect on vision in the yellow. The rise in the curve could scarcely be attributed to the presence of the rods since it does not continue to rise when the rods become even more numerous.

Beyond the fluctuation, which has been considered to mark the boundary of the macula lutea, the critical duration D appears to rise to a maximum about five degrees from the centre of the eye, and then to decrease. Since these measurements were made only to find the general behavior no repetitions were made to eliminate errors, so the points that lie off the curves probably have no significance.

The construction of the eye-piece of the instrument was such that it

did not allow of any readings being taken at a greater angular distance from the centre of the eye than eight degrees, and forty minutes, but it may be predicted from the shape of the curves that the critical frequency would shortly become greater on the periphery than on the centre of the eye. This is in agreement with Allen's measurements.[10] He found that at ten degrees on the temporal side of the retina the criti-

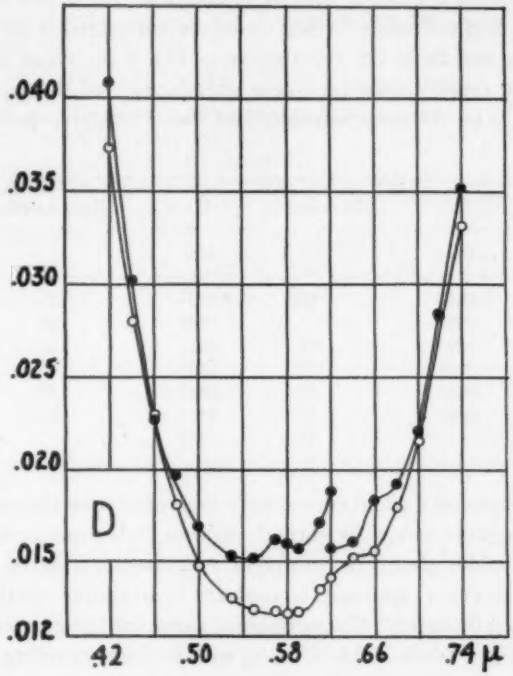

FIG. 5. *Normal foveal and normal peripheral curves. (circles and dots respectively)*

cal frequency was greater than at the fovea centralis, and that at twenty degrees it was still greater. Allen worked with darkness adaptation.

Since but three different wave lengths were used, and these all in the yellow, it cannot be concluded from these data that all the colors will give effects similar to those obtained. On the contrary it is perhaps to be expected, since the macular pigmentation is yellow, that the second curve would gradually merge into the third as the wave length was

changed toward either end of the spectrum. There is, however, evidence from subsequent measurements that there may be other fluctuations in the graph with other colors. These measurements will now be discussed.

As was stated previously, the data plotted in Fig. 4 were obtained in order to find a suitable part of the periphery on which to take a set of normal curves of spectra of varying intensities. The object of doing this was to see if the Purkinje effect could be connected with rod vision. Since at the middle of the third curve in Fig. 4 the value of D did not change very rapidly with the angle, this portion of the periphery was considered to be the most suitable, and was, therefore, used.

TABLE 3.

Wave length	D	Wave length	D	Wave length	D
	sec.		sec.		sec
.74μ	0.0352	.62μ	0.0157	.53μ	0.0153
.72	.0284		.0188	.50	.0169
.70	.0220	.61	.0171	.48	.0197
.68	.0192	.59	.0157	.46	.0227
.66	.0183	.58	.0160	.44	.0302
.64	.0161	.57	.0162	.42	.0409
		.55	.0152		

Eight peripheral normal curves were measured with the same apparatus and procedure as for the normal. After a little practice it was found possible to make about as consistent measurements as on the fovea, the results, however, appeared to conform to no simple relation, so they have not been included. One peripheral curve for the greatest intensity is given in Fig. 5 (data Table 3) along with its corresponding foveal normal. This is for the temporal periphery at 6°5′ from the centre of the eye, the intensity of the spectrum being the same as for the foveal curve. It will be noted that at wave length .62μ two readings are given which are quite different. It was found that at this wave length no consistent readings were obtainable. Those given are the maximum and minimum. This same sort of break occurred at the same wave length in two more of the eight curves and once at 63μ. The length of time over which the measurement was taken did not appear to be a factor in the values obtained. It was suspected that these might be due to the same kind of thing as the breaks in Fig. 4, although it may be related to the anomaly elevation of the foveal curve. At any rate it would appear to be advis-

able before taking preipheral measurements to obtain the kind of data illustrated in Fig. 4 for all the wave lengths to be used.

The writer wishes to express his thanks to Professor Frank Allen of the University of Manitoba, Winnipeg, under whose direction the work was done.

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A COMPARISON OF THE CRITICAL ANGLE OF REFLECTION AND THE INDEX OF REFRACTION OF X-RAYS

By H. E. Stauss*

[Ryerson Physical Laboratory, University of Chicago. Received Aug. 21, 1930]

The index of refraction of x-rays has been determined in a number of ways; by total reflection, the deviation produced by a prism, and the changes in Bragg's law for crystal reflection. No indication has been found that the results of one method do not agree with those of another, but apparently two different methods have not been used on the same sample to the same degree of accuracy. It seems desirable that such a check of the method of total reflection should be made. The assumption that the laws of ordinary optics hold in the x-ray region is a tremendous extrapolation that deserves testing at every possible point. The difference in degree of the properties of visible radiation and x-rays are so marked, e.g., in the photoelectric effect, that the behaviour in one region of radiation cannot be predicted with confidence from that in the other. In the case of x-rays the wave length is comparable with the interatomic distances in solids and with the atomic dimensions themselves. The passage of x-rays through matter is similar to that of light through a gas. The effect of this upon total reflection may be important. The irregularities of a polished surface have a relative importance that they do not have in the visible region. The depth of the disturbance in the reflector is uncertain for these reasons, and yet the penetration of the disturbance may considerably influence the critical angle of reflection. If the penetration is small, a wave length or two at most, the critical angle may be determined by surface conditions and impurities.

In a paper to appear shortly,[1] a method is described for determining the index of refraction by the prism method. The experimental arrangement was such that it made possible a comparison of the results with those determined from the critical angle of reflection for the $K\alpha$ radiation of molybdenum, if the reflector itself was used to pick out the $K\alpha$ line from the general radiation filtered by zirconium oxide. The reflector was midway between the slit acting as source and the photographic plate—the ordinary focusing arrangement for crystal reflection. The angle of reflection corresponding to any part of the reflected beam could be determined by reference to the center of rotation of the mirror. The apparatus was such that it should have been possible

* National Research Fellow.

[1] H. E. Stauss, Phys. Rev., in print.

to straddle the critical angle of reflection with a single reflected line, and thus to determine the critical position very accurately. However, while it was found that two adjacent reflected lines that nearly touched showed good contrast when the critical angle was passed, the critical angle could never be located within a single beam. This may have been because the reflected beam was irregular in density itself and the irregularities disguised the critical angle; or because the cessation of reflection at the critical angle has appreciable width for even this short wave length and for the reflectors of low density used in the experiment.

In order to determine the critical angle, the reflected lines were adjusted until it seemed that the critical angle must lie in one of them. Then it and its neighbors, almost touching it, were photographed and the position of the edge corresponding to the greater angle measured for both it and its darker neighbor. The average was taken as the critical angle. In accord with the physical meaning of probable error, this latter was taken to be one quarter of the measured interval. Very surprisingly, this probable error compares favorably with those which have been obtained with monochromatic radiation.

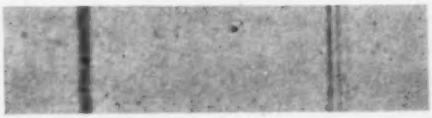

FIG. 1. *The critical angle of reflection of glass. The three reflected lines to the right pass through the critical angle. The contrast between the lines on the left and that on the right is very pronounced. The intensity of the middle line is somewhere between that of the other two, and this line apparently contains the critical angle of reflection.*

The comparison of reflection and refraction was made for a glass and a quartz plate. The measurement of δ was much more accurate in the case of refraction than in the case of reflection, very possibly on account of the nature of the phenomenon of reflection itself as suggested above. Within the limits of error of the experiment, however, the values of δ determined by the two methods are in agreement. The results are shown in the table.

Material	$\delta \times 10^6$ (reflection)	$\delta \times 10^6$ (prism)
Quartz	$1.83 \pm .04$	$1.804 \pm .001$
Glass	$1.68 \pm .03$	$1.643 \pm .003$

Apparently it must be decided that the character of the total reflection of x-rays is such that it is truly characteristic of the body of the reflector and is not influenced to any appreciable extent by surface conditions in the case of a good, polished reflector, even for x-rays of short wave lengths.

INFRARED SENSITIVITY OF CESIUM OXIDE PHOTOELECTRIC CELLS

By James W. Ballard

[Westinghouse Research Laboratory and Physics Department, University of Pittsburgh, Pittsburgh Pa. Received, July 25, 1930.]

ABSTRACT

Measurements have been made of the relative spectral sensitivities of a number of cesium oxide photoelectric cells to visible and infrared radiations. For the region 5000A to 8000A where the results reported here overlap those of Koller and of Vedder, the sensitivities were found to check those previously reported. The infrared response has been found to decrease gradually from the maximum at about 7750A to approximately zero at 12,000A.

Introduction

When light of different colors is allowed to fall on the cathode of a photoelectric cell, the cell does not respond in the same degree to radiations of different colors. By placing the photoelectric cell before a monochromator which separates white light into its various colors, or wave lengths, the response of the photoelectric cell to successive changes in wave lengths may be found. The curve obtained by plotting the current responses of the photoelectric cell against the corresponding wave lengths is the uncorrected photoelectric response curve. With the photo cell replaced by a thermopile, data may be obtained for a similar curve, the uncorrected energy distribution curve. The ratios of the ordinates of the former to the corresponding ordinates of the latter when plotted as a function of the wave length gives the color sensitivity curve of the cell. Thus in accord with the foregoing, the color sensitivity of a photoelectric cell is defined as the current output of the cell per unit rate of incidence of radiant energy for various wave lengths.

Some very good examples of color sensitivity curves of photoelectric cells of all the alkali metals are shown in Miss Seiler's article on "Color Sensitiveness."[1] As we go through the series from Li to Cs, the maximum color sensitivity shifts toward the longer wave lengths and also the curves become broader. She also showed that due to the formation of hydrides of these metals a shifting of the point of maximum color sensitivity occurs toward the longer wave lengths for all alkali metals. Vedder[2] has given color sensitivity curves for cesium-magnesium cells with a maximum at about 3700A. He has also given curves for cesium

[1] Eleanor Francis Seiler, Astrophys. Journ. *25*, 129; 1920.

[2] E. H. Vedder, Electrical Journal, *27*, 152–158; 1930.

oxide cells over a range of 2400A to 8000A with maxima at about 3200A and 8000A and a minimum at about 5500A. Koller[3] has given a similar curve for the cesium oxide cell.

Since for a large number of applications, the photoelectric cell is operated by the radiation from an incandescent solid which has its maximum rate of emission in the near infrared, and since the wave length sensitivity of the cesium oxide cell has been measured only to about 8000A, it has been the purpose of this investigation to extend the sensitivity curve into the infrared.

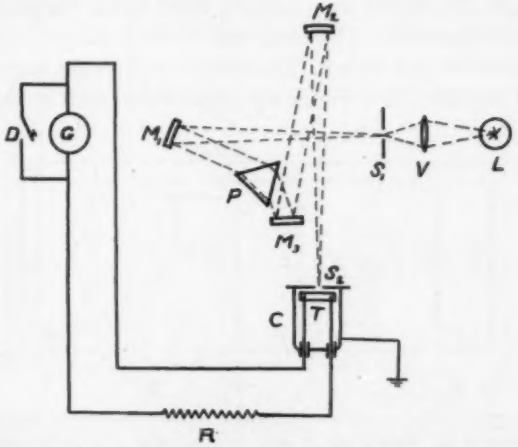

FIG. 1. *Diagram of apparatus used to obtain the color sensitivity of photoelectric cells. The Hilger monochromator of range* 3800A *to* 100,000A *consisted of* S_1 *and* S_2, *two slits;* M_1 *and* M_2, *concave stainless steel mirrors;* M_3, *plane stainless steel mirror; P, rock salt prism; and C, metal shield to ground. The accessories consisted of L,* 200*-watt lamp; V, condensing lens; T, thermopile and also position of photoelectric cell; R, resistance; and G, D, galvanometer and damping key used with thermopile but replaced by direct current amplifier when photoelectric cell is placed at T.*

APPARATUS

1. Lamp. The 200-watt tungsten coiled filament lamp used as the source of light was operated at a temperature of 2870K. The operating temperature of the lamp was obtained with a Leeds and Northrup optical pyrometer by comparison with a standard ribbon filament lamp furnished together with true temperature calibrations by the Research Laboratory of the General Electric Company at Nela Park, Cleveland, Ohio.

2. Monochromator. The dispersing instrument was a Hilger mono-

[3] L. R. Koller, J. O. S. A. and R. S. I. *19*, 135; 1929.

chromator, Fig. 1, with a range of 3800A to 100,000A. The prism was of rock salt and was coated with a solution of pyroxylin in amyl acetate to protect it from moisture. The instrument was calibrated using lines of NaCl, Ne, and Hg. The slits about 11 mm by .13 mm were bilateral and could be adjusted by a large milled ring with divisions reading to .0254 mm. The instrument was quite satisfactory for the work.

3. Photoelectric Cell. The photoelectric cells used in this work were vacuum cells of the central anode type with the cathode in the form of a metal plate, W-shaped cross section, upon which the photo-sensitive material was deposited. The plate was of silver-plated copper, coated with cesium oxide and cesium. The leads were brought out at the opposite ends of the tube. No trouble was experienced with leakage currents.

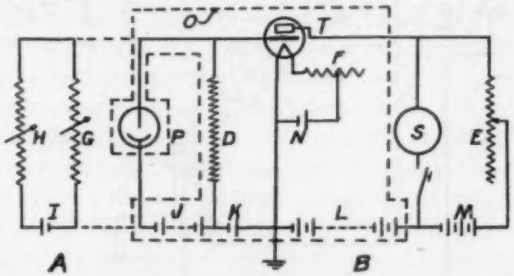

FIG. 2. *Diagram of direct current amplifier used to measure photoelectric current. A, potentiometer arrangement to test characteristic of amplifier; consisting of H, G, two one-thousand ohm variable resistances, I, 1.5 to 4.5 volt battery. B, amplifier consisting of O, copper screen shield; T, UX 201A vacuum tube; P, photoelectric cell; D, 200 megohm; E, 2500 ohms; F and N, filament resistances and battery; J, K, L, and M, batteries of 90, 4.5, 135, and 6 volts respectively; S, milliammeter.*

4. Amplifier. Due to thermo-electric effects and stray magnetic fields around the laboratory, it was very tedious to take color sensitivity curves of a number of photo cells with a galvanometer. A direct current amplifier, Fig. 2, was therefore devised so that data could be obtained quickly and accurately. As the resistance of the photo cell was high, a high resistance *D* of 200 megohms was placed in series with it and the potential drop across this resistance due to the photoelectric current was used to change the grid bias of a UX 201A three electrode radio tube *T*. Thus the photoelectric current caused by a light flux incident on the photoelectric cell could change the plate current of the radio tube by an amount which could be read on a milliammeter. A 2500 ohm resistance *E* was used to control a reverse current through

the ammeter so that when the photo cell was in the dark, the milliammeter deflection was zero, or near zero. Thus when a portion of the spectrum was admitted into the window of the photo cell, a change of deflection was produced on the milliammeter proportional to the light admitted. The linear functioning, Fig. 3, of the amplifier was obtained by adjusting the grid bias so that the amplifier tube operated on the straight portion of the plate current, grid-potential curve. As the amplifier was sensitive to outside disturbances, most of the apparatus was placed in a box shielded with copper mesh and grounded. The

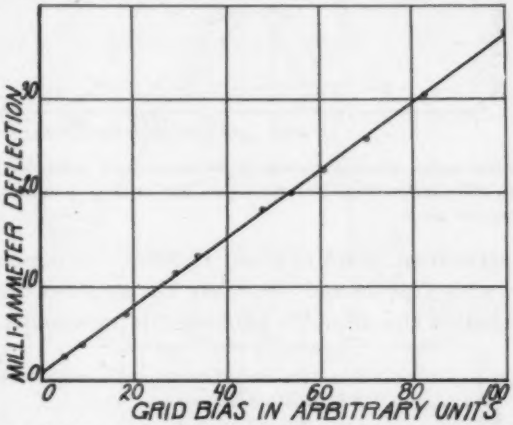

FIG. 3. *Curve showing straight line characteristic of direct current amplifier obtained by replacing photo cell P, Fig. 2, by the potentiometer arrangement A.*

lead from the photo cell to the grid was also shielded with copper-braid tubing. The box was set on rubber sponges. It was found that the amplifier had to be in operation about fifteen minutes to let the batteries and other apparatus become stable before satisfactory readings could be obtained. Otherwise there would be a gradual shifting of the ammeter reading. With these precautions entire curves could be obtained and readily reproduced. The current from the photocell was amplified approximately 10^7 times.

PROCEDURE AND RESULTS

With both slits at about .13 mm, the energy distribution curve for the 200-watt lamp at 2870K was taken over the range 5000A to 30,000A, using a Hilger thermopile of ten elements and a sensitive galvanometer, Fig. 4. The dip in the curve at 20,000A was due to absorption by the pyroxylin coating on the prism. With the slit width unchanged the

thermopile was replaced by a photoelectric cell enclosed in a black box carefully shielded with lead foil on the outside and grounded. The response of the cell as given by the direct current amplifier was found

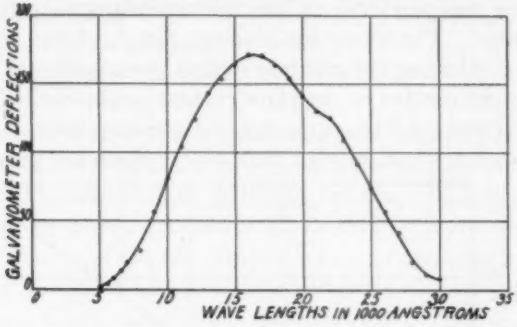

FIG. 4. *Spectral energy distribution curve of an incandescent coiled tungsten filament at 2870°K as taken with a thermopile. This curve has not been corrected to take account of the dispersion of the rock salt prism.*

for wave lengths from 5000A to about 11,000A. No response could be observed between 12,000A and 100,000A. The amplifier characteristics were taken before and after the photoelectric measurements. A re-

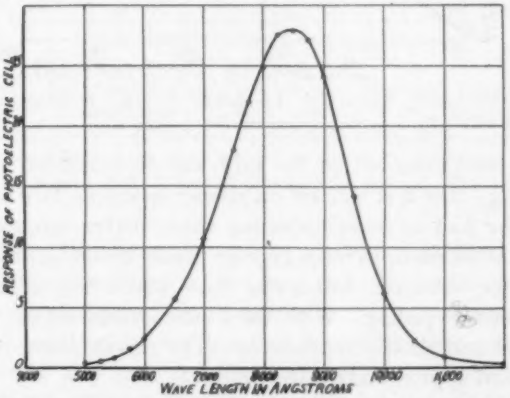

FIG. 5. *Typical gross response curve of a cesium oxide photoelectric cell before correction by thermopile curve, Fig.* 4.

sponse curve as a function of wave length as shown in Fig. 5, was determined for each of the eight photo cells. By dividing the ordinates of the smoothed photo cell curves by those of the smoothed thermopile curve, the wave-length sensitivity curves of the eight cells as shown in

Fig. 6 were obtained. They represent the relative responses of the photo cells to a definite rate of incidence of radiant energy for various wave lengths.

In agreement with the work published by Koller[4] and by Vedder[5] the maximum sensitivity of cesium oxide photoelectric cells was found to lie between 7500A and 8000A with a minimum at about 5500A. In addition the sensitivity was found to extend into the infrared nearly as far as 12,000A.

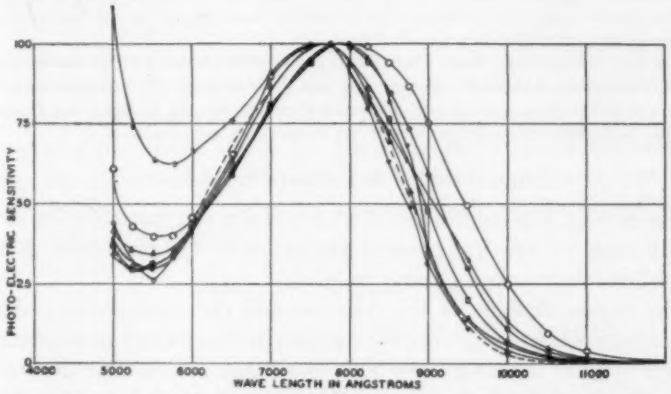

FIG. 6. *Color sensitivity curves (ratio of photoelectric effect to the thermal effect) for cesium photoelectric cells type PV* 51.

Because ordinary incandescent lamps radiate most of their energy in the near infrared, it appears that the cesium oxide cell should be quite efficient for many practical applications.

ACKNOWLEDGMENTS

This work was done at the Research Department of Westinghouse Electric and Manufacturing Company at East Pittsburgh, Pennsylvania.

The writer wishes to express his appreciation to Dr. E. D. Wilson who suggested the problem. He also wishes to thank Mr. S. M. Kintner and Dr. D. Ulrey of the Westinghouse Electric and Manufacturing Company for providing the facilities used in the investigation. He is indebted to Prof. A. G. Worthing of the Physics Department of the University of Pittsburgh for his suggestions in regard to the organization and presentation of the experimental data.

[4] L. R. Koller, *loc. cit.*

[5] E. H. Vedder, *loc. cit.*

CORRELATION OF THE SHADE NUMBERS AND DENSITIES OF EYE-PROTECTIVE GLASSES*

By W. W. Coblentz and R. Stair

[Bureau of Standards, Washington, D. C. Received Aug. 11, 1930]

ABSTRACT

In connection with an extensive campaign for the protection of the eyes of workers from injurious radiation, especially those workers in the Government Service, the Federal Specifications for eye-protective glasses have recently undergone a revision.

The present paper gives technical data proposed to and adopted by the Technical Committee appointed to write these specifications.

The new specifications permit a continuous gradation of shades, without loss of material which is advantageous to both the producer and the consumer. The adoption of a fixed scale of densities gives assurance of uniformity of production and labeling that cannot be changed at the whim of a manufacturer or user of eye-protective glasses.

Formulation of Experimental Data

The present communication gives a revision and amplification of the specification of the transmissive properties of eye-protective glasses, published in a previous paper.[1]

The standardization of the densities and the corresponding shade-numbers of glasses for protecting the eyes from glare and harmful radiation is of great importance to both the manufacturer and the wearer of such glasses. Such an attempt at standardization of shade numbers was called to our attention[2] several years ago by E. D. Tillyer, who suggested the formula

$$\text{Density} = 1/3\ (\text{Shade No.}—1). \qquad (1)$$

In this formula the density has the usual meaning, being equal to the logarithm of the opacity; that is, the logarithm of the reciprocal of the transmission. The advantage of using densities instead of percent transmissions is apparent from the fact that the density is proportional to the thickness of the glass whereas the transmission is an exponential function.

From the data plotted in Fig. 1 (Taken from B. S. Tech. Paper No. 369) it appears that, at that time, manufacturers were using a series

* Publication approved by the Director of the Bureau of Standards, the U. S. Department of Commerce.

[1] Transmissive Properties of Eye-Protective Glasses and Other Substances, W. W. Coblentz and R. Stair, B. S. Technologic Papers, No. 369, *22*, 555; 1928, obtainable only from the Superintendent of Documents, Government Printing Office, Washington, D. C., at a price of 10 cents per copy, prepaid.

[2] In a personal letter dated December 18, 1926 from E. D. Tillyer of the American Optical Company, addressed to W. W. Coblentz.

of shade numbers which could be represented approximately by the formula

$$\text{Density} = 1/3 \text{ Shade Number}. \quad (2)$$

For example, as illustrated in Fig. 1, the densities of different makes of shades 5, 6, 12, and 14 (also shade 15, extrapolated) were found to be in close agreement with formula No. 2, while samples of shades 8 and 10 had an average density which is in approximate agreement with the formula.

On the other hand a certain Government department required glasses having certain transmissions, to which glasses were assigned certain arbitrary shade numbers (6, 8, 10, 12, and 14), illustrated by the upper irregular curve (xxx) in Fig. 1. Recalling Mr. Tillyer's suggestion of formulating the transmission and shade numbers the writers found that the densities of these arbitrarily assigned shade numbers could be represented by the formula

$$\text{Density} = 3/7 \text{ (Shade No.—1)}. \quad (3)$$

This is a close representation of the original, arbitrarily-assigned, shade numbers,[3] the corresponding transmissions of which were then revised to conform exactly with formula No. 3. and used in the Federal Specifications for Eye-Protective Glasses, promulgated in 1927.

Recently, these Federal Specifications have undergone revision. They now include the density of each shade, in addition to the corresponding percent transmission, previously given.

In this connection the most important question was the adoption of a set of tolerances in densities, which would cheapen the cost of manufacture and at the same time provide a glass that will amply protect the wearer from injurious radiation.

Considering the fact that this whole scheme of shade numbers is based upon arbitrarily assigned transmissions, in an unforseen manner it happens that this formula (No. 3) of densities permits a convenient gradation of shade numbers (at least for the shade numbers 2 to 11 inclusive) by adopting a uniform tolerance of ± 0.214 in density. These densities and corresponding percent transmissions are given in Table 1.

For shades 12, 13, and 14, the tolerances appear to be rather small which increases the difficulties in grading these shades of glasses. Hence, in the interest of practicability, the writers would have preferred sac-

[3] See B. S. Technologic Paper No. 369, *22*. 562; 1928.

rificing the formula, widening the range of tolerances of shades Nos. 12 and 14, by eliminating shades 13 and 15, and extending the upper limit in density of shade 14 to include shade No. 15, as illustrated by the dotted curves in Fig. 2. Experience in manufacture, calibration and use will decide whether it is important to adopt a wider range of tolerances than those given in Table 1, for the darkest shades of eye-protective glasses, and a narrower range for shade No. 2.

TABLE 1. *Specification of the transmissive properties of eye-protective glasses, based upon the formula, density, D=3/7 (Shade No. −1)=log (1+Transmission), and the max. and min. tolerances amounting to D=±0.214. The corresponding transmissions are given to the nearest round numbers.*

Shade No.	Density			Percent Transmission		
	Min. Tolerance	Standard Value	Max. Tolerance	Max. Tolerance	Standard Value	Min. Tolerance
2	.22	.429	.63	60.3	37.3	23.0
3	.64	.857	1.06	22.9	13.9	8.6
4	1.07	1.286	1.49	8.5	5.18	3.3
5	1.50	1.714	1.92	3.2	1.93	1.2
6	1.93	2.143	2.35	1.18	.72	.45
7	2.36	2.571	2.78	.44	.27	.166
8	2.79	3.000	3.21	1.62	.10	.062
9	3.22	3.429	3.63	.060	.037	.0230
10	3.64	3.857	4.06	.0229	.0139	.0087
11	4.07	4.286	4.49	.0085	.0052	.0033
12	4.50	4.714	4.92	.0032	.0019	.0012
13	4.93	5.143	5.35	.00118	.00072	.00045
14	5.36	5.571	5.78	.00044	.00027	.00017
15	5.79	6.000	6.21	.00016	.00010	.00006

SUMMARY

The originally proposed shade numbers of eye-protective glasses, with arbitrarily assigned transmissions, are now reduced to a standard formula of densities and corresponding percent transmissions. The adoption of a uniform tolerance of ±0.214 in densities permits a continuous gradation of shades, in whole numbers, without appreciable loss of material in manufacture, although it may cause some inconvenience in the calibration of the densest shades.

The use of a fixed scale of densities gives assurance of uniformity of production and labeling by manufacturers, and uniformity in specification by users of eye-protective glasses.

ERRATUM

Insert this sheet containing Figures 1 and 2 of the Coblentz and Stair paper, to face page 626 of the November issue of this *Journal*.

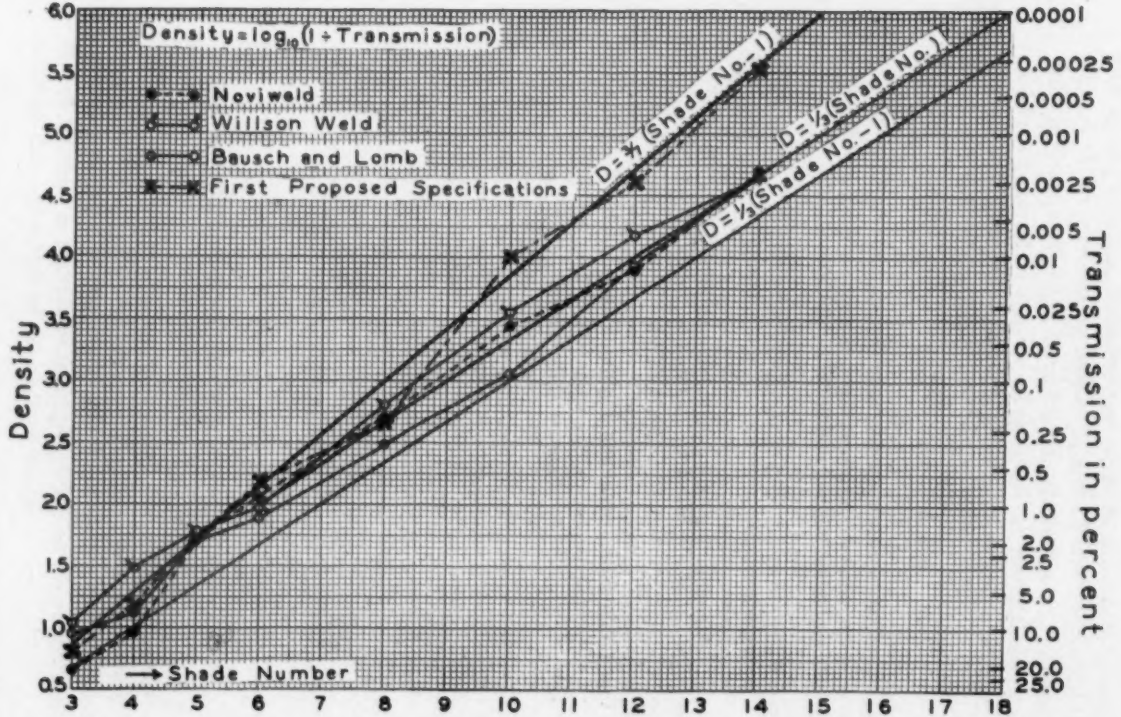

FIG. 1. *Density versus shade number.*

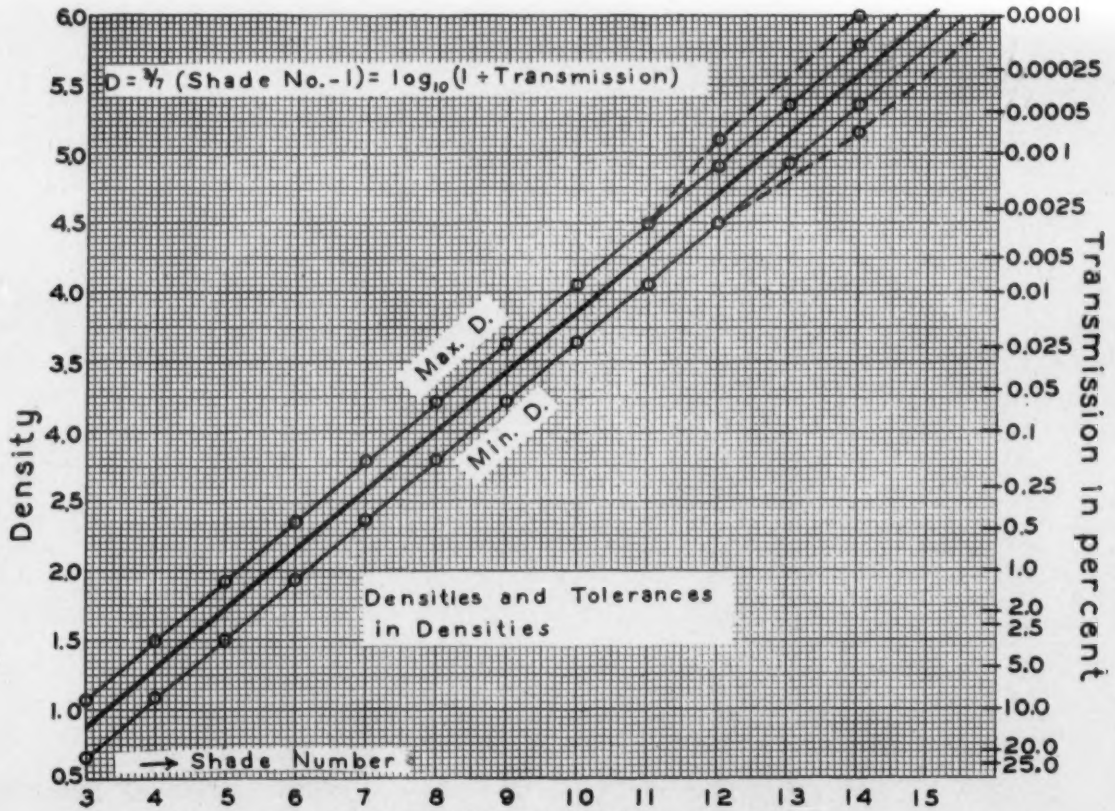

FIG. 2. *Density versus shade number.*

COMMERCIAL GLASS TRANSMITTING ULTRAVIOLET LIGHT

By Paul Davidovich

[Glass Research Institute,
Moscow, U.S.S.R. Received June 13, 1930]

Introduction

It is a well known fact that ordinary glass does not transmit ultraviolet light of the shorter wave lengths. Special glass, however, can be manufactured which will be more or less transparent to the ultraviolet.

For over thirty years high grade UV glass was being used in optical practice, but only a few years ago commercial inexpensive UV glass was put on the market. The latter finds use for window glass as well as for making incandescent lamp bulbs. It may find considerable use also in manufacturing food containers, bottles, jars, etc.

The interest in commercial UV glass has been created through the investigations of biologists on the action of UV light upon living beings. The therapeutic action of rays of short wave length has been known for a long time, but only in recent years was it definitely established that UV light between 2800 and 3100A is endowed with remarkable, not precisely therapeutic but rather merely health-promoting properties.

Light of wave lengths longer than 3100, although still possessing specific action, are however much less active, than those in the interval of λ mentioned above. According to Dorno[1], light of λ3660 is one thousand times less active biologically than that of 2970. On the contrary, light of wave lengths shorter than 2800 are endowed with such a strong action that they produce burns, irritation of the skin and thus become even dangerous if used without proper precautions.

The specific action of light presumably depends in part upon how deep it can penetrate into the skin. The biologically active UV rays do not penetrate more than 0.5 mm, whereas the visible rays between 3900 and 7600 penetrate about ten times farther; i.e., 5 mm or so. We can suppose that the strong action of UV light upon living beings is at least partly due to the fact that the whole energy of short wave-length rays is absorbed within a comparatively thin layer of live tissue. This view finds some support in the fact mentioned by Dorno[1] or Hauser and Vahle[3] that by increasing the intensity of light, an effect similar to the

[1] Dorno C., ZS. für Gesundheitspflege, *8*, 10; 1928.
[2] Coblentz W. W., The Glass Industry, 263; 1927.
[3] Hauser and Vahle, Wissenschaftliche Veröff. des Siemens-Konzerns, *6*, 101; 1927.

specific action of biological UV rays (although not as strong) can be produced also by means of light of longer wave lengths. The chief cause which makes the light between 2800 and 3100 so active biologically, is probably due to the fact that the physical and chemical constitution of the tissues are such that light of wave lengths 2800 to 3100 produced a resonant effect in the living matter.

Within the interval of wave lengths of biological rays not all of them are equally active. The so called sunburn is produced mainly by light of 2900 and 3100 with a minimum near 3000A. The curve of sunburn has two maxima, the one at 3100 having about eight times, and that at 2900 two times stronger action than light of 3000A.

Another important effect of ultraviolet light consists in the fact that it produces the formation of vitamin D in certain foods. It suffices only to illuminate these foods by UV light. Vitamin D is then formed from ergosterin, which absorbs light of 2650 and 2850. The importance of vitamin D can be understood if we mention that, according to the experiments of Windaus and Pohl,[4] one millionth of a gram of this substance is sufficient to cure a rachitis sick rat. Hence the importance of using UV glass for food containers: milk bottles, jars for preserves etc.

Then the biological UV rays, 2800 to 3100; are useful in curing diabetes, anemia, bone-tuberculosis. They also kill bacteria and purify the air.

Certain medical authorities are inclined to ascribe to the biological UV light a number of remarkable properties such as: freeing of white blood corpuscles (leucosytes) and their direction into the sick parts of the body; lowering of blood pressure; increasing red blood corpuscles, of the haemoglobine etc.

Interesting observations on speeding up of partition of live cells under the action of UV light were made in the Siemens Concern Laboratories in Berlin by Reiter and Gabor.[5] The active rays in this case have a somewhat longer wave length: 3400A.

The natural source of UV light is the sun. Assuming its surface (photosphere) temperature to be 6000°, about 1/24 of its total radiation should belong to light shorter than 3000A. However, we do not get much UV radiation from the sun because the earth's atmosphere, mainly the ozone, absorbs all light for $\lambda 1$ shorter than 2896A. Strong VV light can be produced by the various artificial sources of light of

[4] Windaus and Pohl, Naturwissenschaften, 433; 1927.

[5] Reiter and Gabor, Strahlenterapie, *28*, 126; 1928.

which the biological rays, 2800 to 3100, can be filtered out. In addition to the sources of UV light known heretofore we acquired the other day a new and an excellent one—the new General Electric Co. combined arc-filament bulb.[6] The wolfram filament in ordinary incandenscent lamps is, however, not a very good radiator of UV light.

OPTICAL UV GLASS

As early as 1894 Eder and Valenta[7] pointed out that phosphate crown glass posesses very high transparency for ultraviolet light. Later Zshimmer in 1903[8] made an investigation of absorption of UV rays in the various oxides of which glass is being compounded and has established some important facts. It was found that barium oxide Ba_2O_2 shows excellent transparency to UV light. Then, Zschimmer[9] pointed out in 1907 that glasses when freed from alkali metal oxides show an increased transparency to UV light; sodium oxide proved to be less transparent than potassium oxide. Lead oxide showed an especially poor UV transparency. In the same year Fritsch[10] showed that glass containing a generous proportion of boron oxide, B_2O_3, shows excellent transparency to UV rays. The prepared glass of 6 parts of calcium fluoride CaF_2 and of 14 parts of boron oxide which was transparent down to 1850A. Then Fritsch and Lindemann[11] compounded a glass of boron oxide, calcium fluoride and clay earth, which since has been used for spectrographic optics. In the intervening years boron oxide has repeatedly attracted the attention of glass men.

It mentioned here that also lithium glasses are very transparent to light of short wave length. Lindemann[12] prepared a glass of boron, lithium and beryllium oxides which transmits 85 to 90% of x-rays. Whereas the ordinary glass transmits only some 40% of these. Lithium glass in, however, very unstable.

Optical glass transparent for UV light was placed on the market for the first time some three scores of years ago by Schott in Jena, Germany. Later, the Sendlinger Works in Berlin also started the production of such glass.

[6] Luekiesh, General Electric Review, *33*, 89; 1930.

[7] Eder und Valenta, Denkschriften, Wiener, Akademie d. Wissenschaften, Math. Nat. Kl. Bd. *61*; 1894.

[8] Zschimmer, ZS. für Instrumentenkunde, *23*, 360; 1903.

[9] Zschimmer, Physik, ZS., *8*, 611; 1907.

[10] Fritsch, Physik, ZS., *8*, 518; 1907.

[11] Fritsch und Lindemann, ZS. für Physik, 513; 1907.

[12] Lindemann, ZS. für Röntgenkunde, *13*, 141; 1911.

This sort of glass, often called uviol glass, following the lead of Schott, is rather expensive, unstable against atmospheric influences and was being manufactured on a limited scale. It is mostly used for optical instruments.

ABSORPTION OF ULTRAVIOLET LIGHT IN GLASS

The inexpensive commercial UV glass which was introduced on the market and thoroughly advertised, and which is now being manufactured mainly in Germany, is different in some respects from the optical UV glass. Instead of using the highly transparent phosphor oxides, which make the optical UV glass unstable to atmospheric influences, one makes use of ordinary silicon-lime-potassium or lime-sodium glasses only taking care to free them from those ingredients which have a strong UV absorbing power. It is now well established that iron and titanium oxides in the glass are the chief absorbents of UV light, even if added in minute amounts to the comparatively transparent main ingredient of glass, the silicon oxide.*

Therefore the raw materials of which the glass is compounded have to be freed of iron as much as possible.

Sand which forms the main ingredient of glass contains various amounts of iron oxides from 0.005 percent up [Schauer[13]]. The same investigator finds that certain sands contain also some 0.02 percent titanium.

The presence of iron imparts a certain caloration to the sands. Schauer ascribes the greenish caloration of sands to iron silicates, the reddish and brownish—to the iron tri-oxide. Although, the yellowish caloration of sands is sometimes due to coal which is met in amounts up to 0.2%. MacCarthy[14] has made a detailed investigation of natural ferrous silicates and finds that the:

Colorless silicates contain—iron oxide
bluish silicates contain—aqueous compounds of the two and three valency iron.
gray or black—anhydrous compounds of two and three valency iron.
yellow and reddish—compounds of three valency iron.

* For instance G. Rose finds that the absorption of UV light in glass is considerably diminished if instead of calcite (calespar) which contains 0.033 percent of Fe_2O_3, we take lime marl containing only 0.004 percent of iron trioxide.[17]

[13] Schauer, Th. Sprechsaal etc., *58*, 547; 1925.

[14] MacCarthy, G. R. American J. of Science, *12*, 16; 1926.
(Also The American Mineralogist, *11*, 321; 1926.)

green silicates—are a result of a mixture of the partially oxidated bluish varieties with the yellow ones.

Iron in larger amounts imparts also certain colors to glass, which agree in general with the coloration of ferrous natural silicates. According to Heinrichs and Heumann[15] who made the first quantitative study of the problem, the green glass contains the iron dioxide and trioxide in the proportion:

$$FeO/Fe_2O_3 = 0.3$$

whereas the blue glass gives the ratio 2, which means that the blue glass contains a considerably larger proportion of iron dioxide compared to iron trioxide (the same as it is in ferrous sands). The above investigators used glasses with considerable amount of iron up to 1%, which enabled them to use ordinary methods of analysis.

Important contributions to the study of absorption UV rays by iron trioxide were made in the Department of Glass Technology of Sheffield University (England)[16] One of their results, a table given below, shows how the UV transparency of glass is improved with decreasing amount of iron oxides.

TABLE 1.

% of Fe oxides	λ-limit
0.18	3175
0.05	2960
0.015	2740
0.008	2660
0.005	2600

The study of absorption in ordinary glass which contains an appreciable amount of iron does not present especial difficulties, but the problem becomes much more difficult if we turn to UV glass where the amount of iron is very small. As a matter of fact, it is impossible to determine separately the amounts of two and three valency iron in UV glasses. Investigation of UV absorption in water solutions of iron salts may be of assistance here because the UV absorption curves of glass are very much like those of a mixture of water solutions of the two and three valancy iron compounds.

[15] Heinrichs and Heumann, Glastechnische Berichte, *5*, 158; 1927.

[16] Dept. of Glass Technology, Univ. of Sheffield; The Glass Review, *4*, 42; cf. Glastechn. Berichte, *6*, 311; 1928–9.

Such studies, with special reference to UV transmitting glass were made last year in Germany by G. Rose.[17] As a result of these it was found that: (1) the three valency iron absorbs about 100 times more of UV light than the two valency iron; (2) the absorption curve of the two valency iron slowly goes down to 2200A, whereas that of the three valency iron falls down steeply at 3200A; (3) the absorption in a mixture of the two and three valency iron depends upon the relative amount of the two constituents.

The absorption curve of a mixture of the two above salts, as obtained from spectrograms, is followed quite closely by the curve summed up from the curves of absorption by the two and three valency iron compounds.

It appears thus that for the manufacture of satisfactory commercial UV glass the purity of the raw materials especially their freedom from iron, is a matter of prime importance.

However, even if the purest available raws are used, the amount of iron in glass may turn out too large to give a satisfactory transparency for UV light. Since iron dioxide absorbs little of UV rays, reducing means are used in the melting process with the purpose of reducing the three valency oxides of iron into two valency oxides. For this purpose charcoal is used, although when added in larger amounts, it imparts to the glass a muddy yellowish coloration. Zinc chloride is used sometimes, although when added in amounts sufficient to insure good UV transmission it makes the glass hazy. Sodium chloride is not a very efficient means because of its volatility. Bancroft and Cunningham[18] successfully used for reducing purposes (although with no aim to prepare UV glass) hydrogen; this procedure, however, is not always practicable besides being expensive. It is of importance that the amount of oxygen in the melting furnaces should be kept constant if good and uniform results are desired.

It appears that the technique and method of reducing iron in the special case of preparing glasses transmitting UV light has not found until now a rational solution.

An interesting way to prevent the formation of three valency iron suggests a patent of the St. Gobain Company. Manganese peroxide (?) should be added to the glass in order that manganese oxide should undergo oxidation instead of FeO and thus would prevent the higher states of oxidation of iron. This would prevent the drop of transmission

[17] Rose, G., Sprechsaal für Keranmik, Glas etc., *62*, 314, 333, 352, 375; 1929.
[18] Bancroft and Cunningham, J. of Phys. Chem., *34*, 1; 1930.

of UV light because manganese peroxide absorbs these rays in a lesser degree than iron peroxide.

No successful procedure has been as yet developed to get rid of iron oxide (tri-) by means of chlorides, for instance to obtain $FeCl_3$ in the glass.

A few words should be said about the so called decoloration processes, which are intended to make glass colorless. Two ways of decoloration are used in the manufacturing practice. The first can be called chemical, the other physical. The chemical decoloration presupposes the use of such agencies as are capable of changing the substance which imparts coloration to the glass into colorless compounds. In the physical decoloration a substance is introduced into the glass which has a color complementary to that of the given glass; the latter being thus neutralized the glass becomes colorless. Naturally, a certain amount of transparency of the glass is thus lost, as it acquires a neutral gray coloration.

For the manufacturing of UV glass the physical methods of decoloration are of no interest, because the substance which imparts coloration to the glass (say, yellowish tint absorbing UV) is not actually removed but is, only neutralized, and thus the glass retains all of its specific absorbing power; the "coloration" of glass disappears only for the visible rays.

For instance, iron trioxide absorbs UV light much stronger than iron dioxide, and at the same time the trioxide has a yellow coloration, whereas the dioxide a blue-green color. Here is a case where chemical "decoloration" has to be used, if we want the glass to transmit UV light. Reducing substances (see above) may be the chemical discoloring agents in this instance, because they will change the trioxide of iron into a dioxide. Also, "replacing" oxides, such as manganese oxide which easily oxidizes to higher states may be useful.

COMMERCIAL UV GLASS

We will describe now the main features of modern commercial UV transmitting glass. Ordinary window glass does not transmit practically any light beyond 3200A as it can be seen from the adjoining table given by Dorno.[1]

The thickness is given in millimeters. The wave length is A. The figures in the several columns give the percentage of light transmitted at various wave lengths. The table shows clearly that ordinary window glass does not transmit any of the biologically active ultraviolet light.

TABLE 2.

	Wave length in Angstroms							
	Thickness	3400	3200	3100	3000	2950	2900	2700
Window glass	1.8	43	1	0	—	—	—	—
UV window glass "Ultravit" (made in 1927 in Germany)	1.8	85	72	68	54	48	36	6

Other authorities give the same limit, 3200A, for transmission of ordinary glass.

The following extremely interesting table gives the progressive shift of the limit of UV transmission with change of composition. It is taken from the work of Rose.[17]

TABLE 3.

Limit of transmission	B_2O_3	Na_2O	K_2O	BaO	ZnO	Mg_2O_3	PbO	CaF_2	BaF_2
1860A	100	—	—	—	—	—	—	—	—
1860	85	15	—	—	—	—	—	—	—
2260	74	26	—	—	—	—	—	—	—
2750	70	30	—	—	—	—	—	—	—
1990	79	—	21	—	—	—	—	—	—
2450	41	—	—	—	59	—	—	—	—
2100	57	—	—	43	—	—	—	—	—
2310	50	—	—	50	—	—	—	—	—
2450	64	12	12	12	—	—	—	—	—
2800	40	—	—	55	—	5	—	—	—
2800	25	—	—	65	—	10	—	—	—
2260	66	—	—	—	—	4	—	30	—
2570	56	—	—	—	—	4	—	40	—
2570	40	—	—	—	—	—	—	—	60
3460	40	—	—	50	—	—	10	—	—

As it can be seen boron oxide alone transmits light down to 1860A. With the increase of alkali and alkali earths oxides the transparency for UV light decreases and the lower limit of transmission moves towards the less refrangible rays. The sudden increase of absorption produced by magnesium peroxide is suggestive of the great UV absorbing power of iron peroxide (as compared to iron oxide).

However, as we said the more expensive boron oxide glasses can be successfully replaced by special silicate glasses, either of ordinary composition freed from three valency iron, or with a moderate amount of boron oxide.

TABLE 4.

λ	B_2O_3	SiO_2	Na_2O	K_2O	ZnO	BaO
2750	22	58	5	15	—	—
2750	25	15	—	—	15	45
2450	—	78	—	22	—	—
2570	—	68	—	32	—	—

As we have said at the beginning, the light of wave length shorter than 2800A is endowed with therapeutic properties and is dangerous if used without proper care, instead of exercising only health promoting action like the biological 2800 to 3100 rays. From the consideration of table 3 it becomes obvious that much simpler composition, as given in table 4, can be successfully used to prepare commercial UV glass.

Here is one particular case of ultraviolet transmitting glass. Its composition is:

SiO_2	48.3
B_2O_3	23.1
K_2O	17.0
Na_2O	10.3
SnO_2	1.3

its transmission for various wave lengths:

2650A	7.5%
2700	12.4
2750	15.6
2800	32.7
2850	41.3
2890	47.8
2940	52.2
2970	57.2
3020	73.5
3120	81.5.

The modern commercial UV transmitting glassed all show nearly the same transmitting qualities, as can be seen from the following table 5 taken from the paper by Rose.[17]

TABLE 5.

λA	1	2	3	4	5
2600	0.5	0.6	0.5	1	1
2650	2	2	2	3	3
2700	5	5	5	5	6
2750	10	10	10	10	13
2790	20	18	18	20	24
2850	35	31	35	35	35
2890	45	43	45	43	43
2940	57	54	59	50	50
2970	60	58	65	56	55
3020	68	65	73	73	61
3120	78	75	83	74	73
3340	89	89	90	88	88
3400	92	91	91	91	91

The columns give wave length and transmitting power in percents for five various brands of glass: 1—Brevos, 2—Ultravit, 3—Uviol, 4—Sanalux, 5—Vita.

The first four of these are manufactured in Germany, the last one in England (recently also in America).

The average percent transmission of ultraviolet light in the spectral region 2950–3150A for the various brands of commercial UV glass according to Starkie and Turner is given in the following table 6.

TABLE 6.

Corex	89%
Sanalux	73
Sun Ray	62
Holvi	61
Vita	54
Helio	52
Uviol	46
Quartzlite	4
Ordinary window	1

AGEING OF COMMERCIAL UV GLASS

An important problem is whether the UV glass, prepared and used for industrial purposes (window glass, jars etc.) retains its UV transmitting properties and resistance against atmospheric influences. It appears that the Bureau of Standards in Washington was the first to establish that the transparency of UV glass decreases with time.

These observations were ultimately corroborated in other places. Rose[17] made an important contribution to this subject. A piece of commercial UV glass was cut into squares one of which was kept in the dark the other being exposed to UV light from a quartz mercury lamp:

The following extract, from a table given by Rose shows clearly the phenomenon.

TABLE 7.

λA	non-illuminated	Illuminated 2 hrs.	Illuminated 6 hrs.	Illuminated 20 hrs.	Illuminated 30 hrs.
3400	91	89	87	84.5	84.5
2800	20	15	12.5	11	11
2650	2	1.5	0.5	—	—

The transmission was measured by means of spectrograms obtained with a quartz spectrograph. We see that the transmission of light at 3400A changes but little from illumination by UV light. At 2800A the transparency drops down by a half after 20 hrs illumination after which it becomes stable. Still stronger is the effect for 2650A in which case the transmission becomes four times lower already after 6 hours of illumination and after that time no light at all is transmitted by the glass.

Starkie and Turner[19] have studied the drop of transparency of commercial UV glass when illuminated by a carbon arc. They give the following data (table 8):

TABLE 8.

Brand of glass	New	2 hrs.	4 hrs.	6 hrs.
Corex	89	85	82	80
Sanalux	73	65	60	57
Sun Ray	62	51	47	46
Vita	54	44	41	40
Helio	52	43	42	42
Quartzlite	4	3	3	3
Ordinary window	1	<1	<1	<1

The figures indicate the percent of light transmitted by the glass when new and after a 2, 4 and 6 hours illumination. The spectral region was between 2950 and 3150A.

For three brands of glass the percent ratio of two valency to three

[19] Starkie and Turner, J. Glass Technology Society, *12*, 306; 1928.

valency iron oxide was determined for non-illuminated and illuminated glass. The source of light was again a carbon arc, the illumination being 6 hours.

Brand of glass	$\frac{\%FeO}{\%Fe_2O_3}$ Before radiation	$\frac{\%FeO}{\%Fe_2O_3}$ After radiation
Sanalux	48	18
Sun Ray	31	18
Vita	31	21

The result is that the amount of Fe_2O_3 increases after illumination.

If the glass is being melted in platinum, then a certain amount of this metal gets into the glass and decreases its transparency to UV light. This can be seen from the following data.

Limit of transparency	$\%Fe_2O_3$	%Pt
2640A	0.005	0.08
2600	0.005	0.05

Rüttenauer made a study of seven brands of UV transparent glasses of different makers[20] Quartz-glass showed no ageing from illumination, the commercial glasses Osram UV, Ultraviol, Brephos, Bios, Vita and Schott's UV all showed only small aging.

The light of the sun acts in the same way, only much weaker. Peemöller[21] finds that the transparency of ultraviolet light in a commercial glass drops down by 2 to 5 percent after ageing during several months after which it becomes stabilized. Other statements are less favourable. The Bureau of Standards in Washington finds that the well known commercial UV glass Vita after one year of service under sun-light transmits only 25% of light at 3020A, whereas new samples of this glass were letting through 44 percent. A study of the changes of transparency of UV transmitting glasses was made by Schrum, Patten and Smith.[22] The glass was illuminated by x-rays and UV light. Among their results we can mention that the UV glass acquires a feeble coloration, which however fades away if the glass is maintained at 100°. For all samples thermoluminescence effects were observed, as well as solarisation effects. Solarisation faded away if the glasses were heated to 300. The recovery

[20] Rüttenauer, Sprechsaal, *61*, 449; 1928.
[21] Peemöller, Sprechsaal, *61*, 894; 1928.
[22] Schrum, Patten and Smith, Proc. Royal Soc. of Canada; *22*, III; 433; 1928.

from solarisation coincided with the disappearance of thermoluminescence.

S. English[23] states that commercial UV glass which was exposed to daylight (in winter) showed the following changes of transparency; during the first two months an appreciable decrease of UV transparency was observed; for the next two months the drop was slower and by the end of four months the changes stopped.

Ultraviolet light from a quartz lamp gave the same changes much faster—in five to six hours. The same investigator states changes in coloration of commercial ultraviolet glass produced by illumination: the glass has a greenish coloration before illumination, afterwards a yellowish one. The spectroscope reveals a wide absorption band in the green part of the spectrum about 5000A.

Perhaps the same sort of phenomena was observed by Nathanson[24] who has found that the glass (Macbeth-Evans, Company) bells used in ordinary arc lamps after a prolonged illumination obtained a purple coloration.* The green light transparency dropped down from 89 to 83 percent, whereas red and blue transparency remained unchanged. Thus, an absorption band in the green appears.

The nature of the absorption of UV light was first made clear by observations on changes of manganese glasses. These acquire a violet coloration, which is ascribed to reoxydation of the colorless manganese oxide into a violet colored manganese peroxide. For a while such an explanation seemed to be discredited by certain experiments which suggested that the appearance of the violet coloration of glass might be due to the falling out of ultramicroscopic particles of metallic sodium. Indeed, if sodium chloride is illuminated by cathode rays or radium emanation, minute particles of metallic sodium are shed out which can be observed by means of an ultramicroscope. It is there particles that impart a bluish coloration to the glass. It was found that these radiations are able to produce a bluish coloration also in glass. Flowers, Fischer[25] showed that the violet coloration appears only in those glasses which contain manganese. Thus, the explanation turned to be in favour of reoxydation of manganese oxide.

Following this lead, it was surmised that a similar change of iron

* A new brand of glass made by the Company does not show coloration even after 800 hours illumination by a mercury arc.

[23] English, S., Glass, *5*, 338, 388 and 501; 1928.

[24] Nathanson, J. B., Phys. Rev., *17*, 408; 1921.

[25] Fisher, Berichte der Deutschen Chemischen Gesellsch. *38*, 946.

oxides.—reoxydation of iron dioxide into iron trioxide under influence of light—takes place in the glass if the latter is being illuminated. And since the iron trioxide absorbs much more UV light, the glass which was exposed to illumination also absorbs more UV light.

The commercial UV glass shows another kind of instability: its UV transparency becomes smaller if the glass is heated. Rüttenauer[26] finds that the absorption of light between 2800 and 3200A in such a glass is higher by some 20 percent when the glass is heated up to 300 than when its temperature is 20° centigrade.

The phenomenon has not been extensively studied although it is of considerable importance for the production of incandenscent lamps enclosed in UV transmitting bulbs.

It may be of interest to mention here the experiments of Schaum[25] who investigated the absorption in boron and phosphorus beads and shows how the UV transmission drops down with increasing temperature.

Similar experiments were carried out by Funck[27] Heuning and Heuse[28] and others.

We can now draw the following conclusions concerning the manufacturing and properties of commercial UV transmitting glass:

1. The raw materials should be pure and of best quality.

2. The amount of iron and titanium in the raws should be as small as possible.

3. The melting should be carried out in such a way as to change the peroxides into oxides.

4. Such furnaces and melting devices should be used which would not introduce in the melt iron and titanium.

5. The amount of oxygen in the flame of the furnaces should be kept constant.

6. The phosphate glasses are unsuitable (although very transparent to UV light) for commercial purposes because of their high price and also because of their poor resistance against atmospheric influences.

7. The best way to manufacture commercial (window glass, jars etc) glass is to use a nearly ordinary composition of glass, i.e. silicon, calcium and alkali oxides but at the same time to make everything possible to remove iron and titanium oxides and to change the remaining traces of these from three-valency to two-valency states.

[25] Schaum, ZS für Wissenschaftl. Photographie, *23*, 73–78; 1924–5.
[27] Funck, Giessener Dissertation, 1922.
[28] Henning and Heuse, ZS für Wissenschaftl. Photographie, *20*, 132; 1923.

Another, a more expensive, brand can be prepared from silicon, calcium, alcali and boron oxides.

8. Modern commercial UV glass transmits in the biological region (2800 to 3100) some 30 to 80 percent of light respectively.

9. Commercial UV glass is susceptible to ageing: its transparency goes somewhat down when illuminated. The effect is stronger for UV illumination (quartz lamp) than for visible light and becomes stronger for shorter wave lengths of light and also the shorter wave lengths are absorbed stronger. The effect is due to formation of iron trioxide from iron dioxide.

10. The transparency drops somewhat down also if the glass is being heated up.

11. There is indication that the visual coloration of the UV glass changes from greenish before illumination to a brownish after illumination.

The Use of the Microscope. By John Belling, pp. xi+315. New York: McGraw Hill Book Co., 1930. Price : $4.00.

The value of Belling's book on the use of the microscope lies, mainly, in its attempt to acquaint the student with the methods by which the best images can be obtained. It is essentially a practical book, a guide to better use of the microscope rather than an aid in understanding it. Since the book is the outgrowth of the author's personal experiences with the use of the microscope and its accessories it is of more special interest to the biologist.

The arrangement of the subject matter is rather haphazard. Descriptions under subject headings frequently are incomplete, and important points not considered under these headings are found scattered in odd places, making later reference difficult.

The author considers under separate chapters the use of different types of microscopes for different degrees of magnification, the advantages and disadvantages of binocular vs. monocular, methods of illumination, and the advantages of filtered light; these are followed with chapters on the various parts of the microscope. The author justly places particular emphasis on the importance of a well corrected condenser for high power work and the need for correct adjustments of light source, slide thickness, etc.,to obtain maximum usefulness. The latter part of the book deals mainly with the use and care of the microscope. The chapters on photography and drawing are too sketchy and incomplete to be of much value. The chapter entitled "a hundred microscopic objects of biological interest" might very well have been omitted; it seems much out of place since many of the examples are understandable only to a specialized group of biologists to which the author belongs. Likewise, the chapter on fixing and staining microscopic objects should have been omitted. The methods given are those used almost solely in the author's type of research.

A very valuable part of the book lies in the introduction,—where a useful list of causes of injury to the final image with methods of prevention are given. Of particular use to the beginner is the chapter on literature and its accompanying bibliography.

Altho burdened with needless repetition and lacking in orderly arrangement of subject matter the book should be of service because of its many suggestions to students who have an elementary knowledge of the microscope.

BARBARA MCCLINTOCK

Ueber die Entwicklung der Theorie der optischen Instrumente seit Abbe, *von H. Boegehold.* Sonderabdruck aus Band VIII, "Ergebnisse der exakten Naturwissenschaften," Seiten 69–146; Berlin, Verlag von Julius Springer, 1929.

This excellent survey of modern developments and tendencies in the theory of optical instruments during the last thirty years comprises about 75 pages and is divided into six chapters, with the following titles: I. Abbe's treatment of the theory of optical instruments, and special developments of his method; II. Definition and classification of optical instruments: optical imagery and optical projection; III. The various forms of the "eikonal" and the general applications of this method; IV. General laws of optical imagery and projection; V. Systems of revolution around an axis; and VI. Sharp or at least uniform imagery. In the whole field of geometrical optics no more competent authority could have been selected for this task than Dr. H. Boegehold of Jena, who, besides being the leading editor of the last (third) edition of the epoch-making Czapski-Eppenstein treatise on Abbe's theory of optical instruments (Leipzig, 1924) as well as the author of a recent textbook on *Geometrische Optik* (Berlin, 1927), is well known on account of his original contributions in this domain of optics. No important development or trend in geometrical optics within the past quarter of a century or more escapes notice and appraisal in this brief summary, which above all contains a clear account of the far-reaching work of A. Gullstrand in Sweden and of T. Smith in England; and for this reason, if for no other, it should be extremely helpful and useful to most of us who are apt to have some difficulty in following these leaders through mazes of mathematical expressions.

A century ago Joseph Fraunhofer set to work to make spectroscopes and other instruments of precision for the prosecution of his researches. In the short space of his illustrious scientific career he inaugurated a new era in the design and construction of fine optical instruments in Germany, and demonstrated, perhaps on a small scale, the almost limitless possibilities that might flow from such an "eugenic union" as the wedlock between science and industry, a lesson which his clever countrymen were not slow to learn and turn to profit. Some fifty years later the association of Ernst Abbe with Carl Zeiss, a maker of microscopes, etc., in Jena, began to bear fruit in the manufacture of new kinds of optical glass which Fraunhofer had tried to make without much success owing to his limited facilities. This led almost immediately to the construction of unusual new optical instruments on thoroughly scientific lines; and thus about 1885 another new era was started in which over a long period of years until the outbreak of the Great War in 1914, it is scarcely an exaggeration to say, the province of applied optics was almost exclusively German territory. Abbe himself has been called "the Galileo of the microscope," and certainly the impress

of his genius and of his no less remarkable and engaging personality is still to be seen today in the quality of workmanship and in the economic policy of the world-renowned optical firm of Carl Zeiss which he directed for so many years with such signal success and above all in the devotion to his memory that is shown by his colleagues and successors and indeed by all who came in contact with him from the humblest workman in the shop to the highest expert on the staff of optical and mechanical engineers. Abbe's collected writings* consisted mainly of scattered contributions to German and English optical journals on a wide variety of special subjects, all characterized by originality and practical ingenuity; but his complete theory of optical instruments as he taught it in his university lectures was published under his auspices by Dr. Czapski and other colleagues and disciples. It is doubtless true, as Dr. Boegehold says in his monograph here under review, that Abbe's methods and principles are the prevailing ones in use today, certainly in Germany, among those who were his pupils directly or indirectly, and perhaps also to a large extent in other countries also. Nevertheless many individuals are to be found who are disposed to think that in the theory of optical instruments as developed up to the present time not enough importance has been bestowed on the general processes outlined by such earlier investigators as Hamilton and Schleiermacher. Accordingly, while Dr. Boegehold devotes the first chapter of his *résumé* to comparatively recent progress along the lines of Abbe's way of thinking, in the other five chapters he proceeds to discuss in some considerable detail certain fundamental questions that may ultimately lead beyond the boundaries of Abbe's more or less limited horizon.

An illustration may be given of a modern application of Abbe's celebrated theory of ray-limitation, of which, by the way, Huygens seems to have had a pretty clear idea even in his day, as can be seen by referring to Huygens's *Dioptrica*. Formerly, when an optical appliance such as an ordinary magnifying glass, for instance, was used in conjunction with the eye, it was customary to consider the pupil of the eye as constituting an additional stop and generally to assume that it acted as exit-pupil or exit-port of the entire system, unless this office was plainly performed by one of the artificial stops. However, early in the present century certain ophthalmologists, notably Percival, Ostwalt, Tscherning, and Gullstrand, began to insist more and more on the primary importance of the eye-pivot or centre of rotation of the eye; the result being that designers of optical instruments had to make radical changes in their methods of construction. Incidentally, this single consideration led to the development of the modern theory of spectacles, and every spectacle-lens today is ground with reference to the position of the centre of rotation of the eye without taking

* The first half of the fourth volume of the *Gesammelte Abhandlungen*, edited by Professor v. Rohr, appeared only about two years ago.

the pupil of the eye into account except as a wholly secondary factor.

Modern optical instruments are so various and are employed in such widely different ways in the arts and industries and for purposes of entertainment and amusement as well as for serious scientific investigations that it has become almost impossible to devise a definition that will cover every type of appliance. It is perhaps equally difficult to say exactly what is meant by an optical image and to give a definition of this common term that would include, for example, the image formed by a photographic lens and that projected on a screen by a pinhole camera. While such questions may seem more or less academic, nevertheless they are found to be of quite fundamental importance for the formulation of a general theory of optical instruments; and so Dr. Boegehold devotes nearly the whole of his second chapter to the definition and classification of optical instruments on the one hand and to the distinction between "optical imagery" and "optical projection" on the other hand. This latter distinction is one that is much emphasized by Gullstrand in his writings; and in this chapter also Dr. Boegehold gives a bare outline of the powerful method of investigation used by Gullstrand which is quite different from that of his predecessors, nearly all of whom (except Hamilton) have proceeded on the assumption that the optical instrument was symmetrical around an axis and composed usually of a series of spherical refracting (or reflecting) surfaces. Thus for example, the great Munich mathematician Seidel developed the so-called aberrations or faults in the actual image as compared with the ideal image of Gauss's theory in a series of ascending powers of the diameters of the aperture and field of view in which the upper terms could be more or less disregarded according to the degree of approximation that was considered sufficient for practical purposes. On the other hand, Gullstrand (whose optical contributions date from about 1890) starts with the law of Malus, and by successive differentiations of his fundamental equation, he investigates the immediate surroundings of a particular ray and the nature of the caustic surface at any place along this ray. In both conception and execution it is a method of the utmost generality and at the same time a process of exploration that is like throwing a searchlight into a dark corner; only it takes an expert manipulator like Gullstrand himself to employ it with real success.

About a century ago Sir William Rowan Hamilton published a series of brilliant mathematical papers in the *Transactions of the Royal Irish Academy* in which he developed the theory of a so-called "characteristic function" of a system of rays of light; and although in its general outline as Hamilton expounded it, the method has never seemed to be quite applicable to the actual problems of the optical engineer, it has always had a certain fascination for writers on geometrical optics on account of its simplicity and generality. The function called the "eikonal" which was found inde-

pendently by Professor H. Bruns in 1895 is a still further generalisation of Hamilton's characteristic function, and, as has been already stated, the third chapter of Dr. Boegehold's essay treats of the various kinds of "eikonal" and their applications in general. Interest in Hamilton's original work and in Bruns's methods has been revived recently by T. Smith in England, who in his presidential address in 1926 before the Optical Society of London lamented the fact that Hamilton's work had been so long neglected, and who since that time has published a number of valuable articles on the subject, although it must be admitted they are not easy reading for the unitiated. Here Dr. Boegehold comes to the rescue in Chapters III, IV and V of his monograph and gives us a summary of Smith's results together with a comparison between them and those of Gullstrand. This is a lucid exposition which can be followed without much difficulty, and will prove of great help to the student of modern geometrical optics.

Finally, in Chapter V Dr. Boegehold discusses recent extensions of Abbe's celebrated "sine condition" which is the criterion of a sharp image in the centre of the field. From the practical as well as from the theoretical point of view this is likewise a subject of much importance, but owing to lack of space we can only allude to it here. At the end of the last chapter the author comes somewhat regretfully to the conclusion that it is practically impossible to obtain a sharp image of a finite area with an optical system consisting of a limited number of refracting surfaces.

JAMES P.C. SOUTHALL